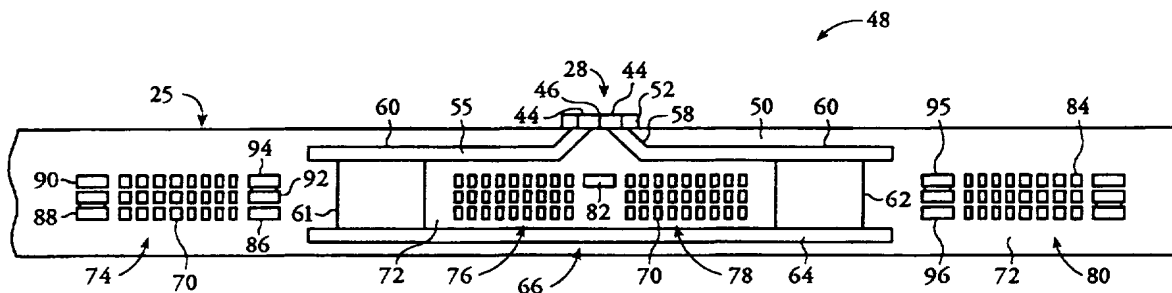




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(54) Title: CONTACT PLANAR RING HEAD



(57) Abstract

A transducer (48) for a hard disk drive has a magnetic core (66) and a pair of poletips (44) that project transversely from the core for sliding contact with the disk during reading and writing. The transducer is formed entirely of thin films in the shape of a low profile table having three legs that slide on the disk, the poletips being exposed at a bottom of one of the legs for high resolution communication with the disk, the throat height of the poletips affording sufficient tolerance to allow for wear. The transducer includes a loop shaped core of magnetic material that ends at the poletips, the core extending further parallel than perpendicular to the disk surface. The dimensions of the yoke adjacent to the poletips are designed to avoid saturation at the poletips by saturating at a lower flux in the yoke than the poletips.

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## CONTACT PLANAR RING HEAD

### Cross Reference to Related Applications

5           This application is a continuation-in-part of pending U.S. Pat. Appl. Ser. No. 08/515,140, filed August 15, 1995, and is also a continuation-in-part of pending U.S. Pat. Appl. Ser. No. 08/338,394, filed November 14, 1994. All of the above materials are hereby incorporated by reference into this application.

### 10   Technical Field

          The present invention relates to hard disk drive systems having transducers including a magnetic core with a gap adjacent to a magnetic storage disk.

### Background of the Invention

15           Hard disk drives have traditionally employed electromagnetic transducers that are spaced from a rapidly spinning rigid disk by a thin layer of air that moves with the disk surface. Such an air layer helps to avoid damage between the rapidly spinning disk and the essentially stationary transducer, which is constructed with a large, aerodynamic “slider” designed to “fly” over the surface, buoyed by the moving air layer. The air layer,  
20   however, creates an additional space between the transducer and the magnetic medium of the disk that is used to store information. This spacing lowers the density with which data can be stored and lowers the resolution and amplitude with which data can be retrieved.

Conventional flying heads have a pair of poletips formed by thin film processes on a back end of the slider and terminating coextensively with the slider air bearing surface. In flight, the slider is tipped so that the back end is lower than the front end and the poletips are closer to the disk than the remainder of the slider. Other flying heads, representative of which is U.S. Pat. No. 4,698,708 to Lazarri, have poletips that are flush with the air bearing surface of the slider partially between the front and back ends.

In an attempt to lower the spacing loss and thereby increase resolution and amplitude, transducer flying heights have generally decreased over many years in the magnetic recording industry. Lowering the flying height, however, encounters a countervailing problem of catastrophic head crash that occurs when the transducer impacts the rapidly spinning disk. In recent years a solution to the conflict between flying height and head crash has been achieved by designing the drive system so that the head supporting structure is run in continuous sliding contact with the disk, which can reduce the problem of impact between the head and disk and decrease the spacing between the head and disk. Any perturbation that causes separation between the head and disk, however, can result in a crash when the two recontact. Such a perturbation can be due to a shock to the drive, such as would occur from accidental bumping of the drive or its support, or can be due to the presence on the disk surface of an asperity or debris. Note that in either situation, a potentially destructive impact can occur due to the initial perturbation, instead of or in addition to the crash upon recontact.

In U.S. Pat. No. 5,041,932, Hamilton discloses a transducer that operates in contact with a rigid disk surface without destructive head crash, essentially by designing

the mechanical and inertial characteristics of the transducer to conform to the rapidly spinning rigid disk without damage to the disk or transducer. A different approach for a hard disk drive system for allowing operational contact between the head and the disk is disclosed in U.S. Pat. No. 4,819,091 to Brezoczky et al., which proposes that

- 5 nondestructive wear may be possible provided that the slider material is so much more thermally conductive than the disk that the slider surface is maintained at a lower temperature than the much larger disk surface as the slider rubs on the disk. And U.S. Pat. No. 4,901,185 to Kubo et al. teaches operational contact between a disk and a slider having a head appended and spaced from contacting the disk to avoid damage to the head.
- 10 More recently, U.S. Pat. No. 5,327,310 to Bischoff et al. teaches a transducer similar to that disclosed in the Hamilton patent but having a ring-shaped transducer mounted vertically on a trailing end of a slider that makes intermittent, bouncing contact ("pseudo-contact") with the disk.

- An object of the present invention is to provide a transducer optimized for
- 15 minimal head-medium spacing during longitudinal recording on and reading from the medium. A related object is for such a transducer to be stable and biased toward contact with a disk surface without the need for excessive force to hold the transducer to the surface against the lifting force of an air layer that moves with the disk, thereby avoiding problems of vibration and damage to the disk and/or transducer. In concert with the
- 20 above objects it is desired to provide a transducer having efficient electromagnetic signal transduction.

### Summary of the Invention

The above objects are achieved with a transducer shaped like a low-profile table with three short support legs that slide on the medium surface during information transfer between the transducer and the medium. The transducer includes a magnetic core which stretches like a shallow, symmetric loop within the plane of the table, with ends of the loop extending into one of the legs to form a pair of closely spaced magnetic poletips exposed to the disk surface in close proximity to the medium. Inductively coupled to the core is a conductive coil that spirals in opposite directions around laterally opposed sections of the core, the spirals stacked like pancakes centered on the opposed core sections. The core and the coil extend substantially further in the plane of the table top than along the direction with which the legs project, affording the mechanically and aerodynamically favorable low profile shape. The table top may be T-shaped or trapezoidal, reducing the mass of the transducer and increasing the number of transducers that can be obtained per wafer while retaining three-legged stability.

During writing of information to the medium, a current in the coil creates a magnetic field along the length of the loop shaped core, creating a magnetic field that spans the microscopic gap between the ends of the core and induces a similarly directed magnetic field in the adjacent media layer. Since the poletips are in contact with the disk surface and have an extremely small gap, very high resolution writing of information can be accomplished with this system. Unlike conventional heads which have tight tolerances for vertical throat height, the dimensions of the planar core of the present invention allow the throat height to vary substantially without impeding writing and

reading efficiency, affording tolerance for wear of the sliding poletips. Additionally, the planar core allows the head to assume a relatively flat, stable, low-profile conformation with lower moment arms about the head-disk contact area, including both a lower moment of inertia of the chip and a lower effective mounting point of the beam holding  
5 the chip.

Reading of magnetic patterns imbued in the medium occurs due to the changing magnetic field seen by the poletips from the spinning disk on which the tips slide, creating a voltage in the inductively coupled coil that is read as a signal. Due to the intimate contact between the poletips and the recording surface, very high signal  
10 resolution and amplitude is achieved. In order to increase the high frequency permeance of the head, the core is formed of elongated strips, layers or filaments. Additionally, the poletips may be coated with a high magnetic saturation material adjacent to the gap in order to provide an intense magnetic field across the gap without saturation, even at field strengths of up to and exceeding 10,000 Gauss. In a preferred embodiment, the core is  
15 shaped like a clamshell, allowing formation of several coil layers within the core without unnecessarily increasing the reluctance of the core.

The low-profile, three-legged transducer is attached via a gimbal to a load beam to present a dynamic configuration that closely and rapidly conforms to a spinning disk so as to maintain contact and high resolution communication with the medium. Due to the  
20 small legs, which act like short stilts lifting the rest of the transducer above the thin moving air layer that adjoins the disk, little of the transducer is impinged upon by that thin moving air layer, and so minimal lifting force is generated that must be overcome to

maintain contact. The interconnection between the transducer and the gimbal is made with exposed conductive bumps that pierce and are anchored to an outer insulative layer of the transducer, providing mechanical as well as electrical connections. The transducer is built in layers, along with many other transducers, on the surface of a wafer substrate  
5 from which the transducers are later removed, allowing the transducer to be much smaller and lighter in weight than conventional transducers that include bulk substrate materials. The legs, including the magnetically active leg containing the projecting poletips, are formed last, allowing careful tailoring of the most sensitive portions of the transducer.

#### 10 Brief Description of the Drawings

Fig. 1 is an enlarged perspective view of a generally plank-shaped embodiment of a transducer of the present invention with three disk-facing projections.

Fig. 2 is a bottom view of the transducer of Fig. 1.

Fig. 3 is a cross-sectional view of a magnetically active portion of the transducer  
15 of Fig. 1.

Fig. 4 is an opened up bottom view of the magnetically active portion of Fig. 3.

Fig. 5 is a further enlarged bottom view of the magnetic pole structure of Fig. 4.

Fig. 6 is a cross-sectional view of an early step in a fabrication process of the transducer of Fig. 1, showing the formation of a conductive etchable release layer for the  
20 transducer on a wafer substrate.

Fig. 7 is a cross-sectional view of a later step in the process of Fig. 6, showing the formation of a gold interconnect button for the transducer.



Fig. 8 is a cross-sectional view showing a later stage in the process of Fig. 6, including formation of an interconnect stud.

Fig. 9 is a cross-sectional view showing a later stage in the process of Fig. 6, including construction of magnetic yoke layer, magnetic stud section and conductive coil  
5 section.

Fig. 10 is a top view of formation of the magnetic yoke of Fig. 9 by window frame plating.

Fig. 11 is a cross-sectional view showing steps in the formation of magnetic stud and conductive coil sections subsequent to those shown in Fig. 9.

Fig. 12 shows an opened up top view of one of the coil layers formed by the  
10 process of Fig. 10.

Fig. 13 is a cross-sectional view of the formation of an amagnetic pedestal on a layer between ends of the magnetic studs formed by the process of Fig. 10.

Fig. 14 is a cross-sectional view showing the construction of a magnetic yoke on  
15 the layer and pedestal of Fig. 14, the yoke having ends extending transversely toward each other.

Fig. 15 is a cross-sectional view showing the formation of a first magnetic pole layer and amagnetic gap structure on the extending yoke ends of Fig. 14.

Fig. 16 is a cross-sectional view showing the formation of a second magnetic pole  
20 layer adjoining the amagnetic gap of Fig. 15.

Fig. 17 is a cross-sectional view showing angled, rotating ion beam etching of the pole layers to form tapered poletips.

Fig. 18 shows a top view of the pole layers and etch mask of Fig. 17.

Fig. 19 is a cross-sectional view showing the formation of a hard protective layer on the tapered poletips.

Fig. 20 is a cross-sectional view showing the formation of a layer of high  
5 magnetic saturation material on the pole layer adjoining the gap.

Fig. 21 is a cross-sectional view showing the formation of layers of high magnetic saturation material on both sides of the gap.

Fig. 22 is a top view showing the formation of a pair of laminated magnetic studs for connecting top and bottom yokes.

10 Fig. 23 is a top view showing the formation of an alternative embodiment of laminated magnetic studs.

Fig. 24 is a cross-sectional view of the formation of a laminated top yoke.

Fig. 25 is a top view of the formation of a laminated top yoke of Fig. 24.

Fig. 26 is a cross-sectional view of a laminated, clamshell shaped magnetic core,  
15 including the top yoke of Fig. 24 and the laminated studs of Fig. 22.

Fig. 27 is a cross-sectional view of a laminated, clamshell shaped magnetic core, including the top yoke of Fig. 24 and without any magnetic studs.

Fig. 28 is a bottom view of a T-shaped chip of the present invention.

Fig. 29 is a top view of a pair of trapezoidal chips of the present invention.

20 Fig. 30 is bottom view of a flexure beam and gimbal attached to the T-shaped chip of Fig. 28 to form a head gimbal assembly (HGA).

Fig. 31 is an opened up top view of a disk drive employing the HGA of Fig. 30.

### Description of the Preferred Embodiment

Referring now to Figs. 1 and 2, a greatly enlarged view of a transducer 20 of the present invention has a generally plank shaped chip 22 with a surface 25 designed to face  
5 a recording surface of a rigid magnetic storage disk. The transducer has a magnetically active pad (MAP) 28 that projects from the disk-facing surface 25 at a location adjacent to a first end 30 of the chip 22 and approximately equidistant between a right side 33 and a left side 35 of the chip. A pair of magnetically inactive pads (MIPS) 38 and 40 project from the disk-facing surface 25 adjacent to a second end 42 of the chip 22, MIPS 38 and 40 being  
10 disposed about the same distance from side 33 as MIPS 40 is from side 35. The three pads 28, 38 and 40 are spaced apart from each other to provide a stable support structure for the transducer 20, like a table with three short legs that can maintain contact with any conventional disk surface. An exposed pair of magnetic poletips 44 are located on a bottom surface of MAP 28, with an amagnetic gap 46 disposed between the poletips 44.  
15 The poletips 44 are ends of a loop-shaped core of magnetic material that is embedded in the chip 22 and not shown in this figure.

As a descriptive aid, a direction generally corresponding to that in which the MAP 28 and MIPS 38 and 40 extend from the surface 25 is termed the "vertical" direction, while an orthogonal direction along the length of the sides 33 and 35 is termed the  
20 "longitudinal" direction. A direction orthogonal to both the vertical and longitudinal directions and corresponding generally with an elongated direction of ends 30 and 42 is termed the "lateral" direction. Elements of the chip 22 designed to be closer to a disk are

commonly called "bottom" elements while those that will be employed further from the disk are called "top" elements, although a typical disk will have a chip 22 sliding on both disk surfaces. Moreover, as will be seen, the chips 22 are built in layers beginning with the side that will be positioned furthest from the disk, so that during production some

5 "top" elements are formed beneath some "bottom" elements.

The loop-shaped core extends within a transduction section 48 further in the longitudinal direction than in the vertical or lateral direction, and is inductively coupled within that area 48 to a coil which winds repeatedly around the core, as will be seen in greater detail below. The protrusion of the poletips 44 from the disk-facing surface 25

10 allows the core to contact the disk, reducing the spacing between the core and the media layer of the disk while lifting the disk-facing surface of the chip 22 from the influence of the thin film of air moving with the disk. As will be seen, the entire chip 22 is constructed of a composite of thin films, and any bulk substrate which was used as a work surface for forming many thousands of such chips is removed after formation of the

15 chips. This thin film composite chip 22 is much lighter than conventional sliders which include bulk substrate, the lighter weight decreasing the inertia of the chip and the power of impacts between the chip and a hard disk, thus reducing the probability of damage.

The chip 22 may have a thickness measured in the vertical direction between the disk-facing surface 25 and an opposed major surface, not shown in this figure, of between

20 about 1 mil and about 5 mils, although other thicknesses may be possible, depending upon tradeoffs such as magnetic constraints and mass. The lateral width of this embodiment of the chip 22 is about 20 mils, although this width can vary by more than a

factor of two and is set primarily by the separation of the MIPS 38 and 40 required for stability. The width can be much smaller about the MAP 28, as discussed below, while still encompassing the transduction section 48. The MAP 28 and MIPS 38 and 40 extend from the surface 25 an approximately equidistant amount, which may range between

5 about 2  $\mu\text{m}$  and 8  $\mu\text{m}$ , which is sufficient to avoid aerodynamic lifting and to allow for gradual wear without engendering fracturing of those pads or instability of the transducer

20. The aerodynamic lifting force is believed to be primarily due to the disk-facing area of the chip which is in close proximity with the disk, including the contact area of the pads, and any bowing or tilting of the chip. As will be explained in greater detail below,

10 the chip 22 may be intentionally bowed, tilted and/or etched to create a negative pressure region between the chip 22 and the spinning disk, so that the lifting force from the disk-facing area of the chip is more than overcome by downward force of the negative

pressure. An area 50 of each of the MIPS 38 and 40 may be as small as 25  $\mu\text{m}^2$  or as large as about 1000  $\mu\text{m}^2$ , although other sizes are possible based upon tradeoffs

15 including, for example, friction, pad wear and manufacturing tolerances. An aspect ratio of the vertical height to the lateral or longitudinal width of those pads should not be much over 2/1 to avoid fracturing and transducer inefficiency. The length of the chip 22 of this embodiment as measured between the first end 30 and the second end 42 is about 40 mils, although this can be varied by a factor of two. This aspect ratio is determined primarily

20 by mechanical considerations regarding the separation of the MIPS 38 and 40 and the MAP 28, as limited by the space needed for the transduction section 48.

In Fig. 3, a cross-section of the chip that focuses on the transduction section 48 is shown along a cross-section bisecting the MAP 28, the poletips 44 and the gap 46. A lower layer 50 which preferably is made of alumina, but which alternatively may be made of another electrically insulative, amagnetic material such as doped silicon, silicon dioxide or diamond like carbon (DLC) forms the disk-facing surface 25, while a hard, wearable casing 52 which is preferably made of DLC or another hard amagnetic material such as silicon carbide or boron nitride forms the portion of the MAP 28 surrounding the poletips 44. The gap 46 is preferably formed of an insulative, amagnetic material such as silicon or silicon dioxide which is softer than the hard wear material of the casing 52.

Hydrogenated carbon is a desirable gap 46 material, having a hardness that can be adjusted to correspond with the particular poletip 44, casing 52 and disk surface characteristics. The wear material of the casing 52 is preferably made of an amorphous material such as DLC which has a hardness similar to that of a surface layer of the disk with which the transducer 20 is to be employed, for matching wear between the transducer and the disk. The casing may be thicker closer to the disk-facing surface 25 for manufacturing and durability. Adjoining the poletips 44 is a bottom yoke 55 of magnetic material which extends symmetrically from a pair of slanted sections 58 to a pair of generally planar sections 60. The poletips 44 and yoke sections 58 and 60 are formed from permalloy or other known magnetic materials, while at least one of the poletips may include a high magnetic moment material, such as cobalt niobium zirconium (CoZrNb), iron nitride (FeN) or iron nitride alloys such as FeNAl adjacent to the gap 46. The yoke sections 58 and 60 are preferably formed in a laminated fashion, to be described

below, in order to reduce eddy currents that impede transducer efficiency at high frequencies. Adjoining the yoke sections 60 are a pair of magnetic studs 61 and 62 that extend to a generally planar magnetic top yoke 64 interconnecting the studs 61 and 62. The poles 44, bottom yoke 55, studs 61 and 62 and top yoke 64 form a generally loop-shaped magnetic core 66, creating a contiguous magnetic circuit except for the small amagnetic gap 46. In a preferred embodiment discussed below, the studs are eliminated, and the core is formed in a shape having a cross-section that resembles a clamshell.

A series of electrically conductive coil sections 70 made of copper or other conductive metals or alloys is shown in cross-section in Fig. 3 to be spaced both within and without the magnetic core 66. Interspaced between the coil sections 70 and the core 66 is an electrically insulative spacer material 72 such as  $\text{Al}_2\text{O}_3$ ,  $\text{SiO}_2$  or a hardbaked photoresist or other polymer. The coil sections 70 can be seen to be divided into three generally horizontal layers in this embodiment, although more or less layers are possible, depending upon manufacturing and magnetic tradeoffs. These layers of coil sections 70 can also be seen to fall into four horizontally separate groups. Proceeding from left to right, these groups are labeled 74, 76, 78, and 80, with a crossover section 82 connecting groups 76 and 78. Although difficult to see in the cross-sectional view of Fig. 3, the coil sections 70 are in actuality a single coil 84 which winds repeatedly about first one and then the other of the two studs 61 and 62. The groups 74 and 80 which are disposed outside the core 66 have an electric current during writing or reading which is directed into or out of the plane of the paper opposite to that of groups 76 and 78 and crossover

section 82. The reader may wish to jump ahead temporarily to Fig. 12, which shows a top view of one layer of the spiraling coil 84, including crossover 82.

Thus a current traveling into the plane of the paper at coil section 86 would spiral in the layer of that section 86 around stud 61 with a generally increasing distance from the stud 61 until reaching section 88, which is connected to section 90 of the next layer. The current would then spiral inwardly about stud 61 in the layer of section 90 until reaching section 92, which is connected to section 94 of the next layer. The current would then spiral outwardly around stud 61 in the layer that includes section 94 until reaching crossover section 82, at which point the current would begin to spiral inwardly about stud 62, traveling to the second layer at section 95. The layered spiraling of the current around stud 62 would continue in a similar but converse fashion to that described above for the spiraling about stud 61, until the current exited the coil structure by traveling out of the plane of the paper at section 96. The coil 84 thus resembles interconnected stacks of pancake-shaped spirals centered about studs 61 and 62.

Representative dimensions for this embodiment include an approximately 3  $\mu\text{m}$  thick bottom yoke 55 and a top yoke 64 that is about 4  $\mu\text{m}$  in thickness, and studs 61 and 62 which each extend vertically about 23  $\mu\text{m}$  between the yokes. The thickness of the bottom yoke 55 is selected to saturate at a somewhat lower magnetic flux than the poletips, thus limiting the flux through the poletips and avoiding broadening of the transistion that would occur during poletip saturation. In order to achieve this flux limiting effect with poletips of different sizes and materials, a function can be employed to determine the optimum bottom yoke parameters. The individual coil sections 70 are



about 3.5  $\mu\text{m}$  thick measured in the vertical direction, and have a center to center spacing of about 5.5  $\mu\text{m}$  in that direction. Longitudinally, those sections 70 may be about 2  $\mu\text{m}$  to 4  $\mu\text{m}$  thick within the core 66 with a center to center spacing of about 4  $\mu\text{m}$ . The top yoke 64 extends about 169  $\mu\text{m}$  longitudinally, and the bottom yoke 55 extends similarly but is, of course, split up by the poletips 44 and gap 46.

In Fig. 4, a top view diagram of the magnetic core 66 shows that the bottom yoke 55 is shaped like a bow-tie, as the slanted sections 58 are much narrower in lateral dimension than the planar sections 60. Diagonal tapered portions 100 of the planar sections 60 funnel magnetic flux into the narrower section 58 during a write operation and offer a low reluctance path for such flux during a read operation. Centered atop the slanted sections 60 are the poletips 44, which are separated by the amagnetic gap 46. The planar sections 60 have a width, excluding the tapered sections 100, of about 42  $\mu\text{m}$ , which tapers at about a 45 degree angle to a width of about 7  $\mu\text{m}$  at the slanted sections 58. The studs 61 and 62 meet the planar sections 60 distal to the poletips 44.

An even more enlarged view in Fig. 5 shows that the poletips 44 are shaped like baseball homeplates that nearly meet along parallel sides, separated by the long, narrow gap 46. The poletips 44 and gap 46 are exactly tailored to precise dimensions that are chosen based on a number of parameters. The specific embodiment depicted in Fig. 5 has poletips that each measure 3.25  $\mu\text{m}$  in the lateral dimension and 4  $\mu\text{m}$  in the longitudinal direction, before tapering to extend another 2  $\mu\text{m}$  longitudinally. The peak-to-peak longitudinal dimension of the poletips 44 and gap 46 is 12  $\mu\text{m}$ . The gap 46 has a precisely defined longitudinal dimension of 0.26  $\mu\text{m}$  and a lateral dimension of 3.25  $\mu\text{m}$ .

Beginning with Fig. 6, a process for making the chip 22 is shown. Atop a ceramic wafer substrate 110 such as silicate or hot pressed  $\text{Al}_2\text{O}_3/\text{TiC}$  which has been cleaned and of which a small portion is shown, a sputtered seed layer 112 of titanium copper (Ti/Cu) of between about 1000 Å and 2000 Å is formed in two steps, by first sputtering a layer of Ti and then sputtering a layer of Cu. The seed layer 112 allows electroplating of a copper (Cu) release layer ("CuRL") 114 which merges with the seed layer 112. The CuRL 114 provides, as will be seen, eventual release of a large number of formed chips 22 from the substrate 110. Other selectively etchable conductive materials could instead be used, but copper offers a highly conductive, cost effective choice for this purpose. The CuRL 114 is formed to a thickness of about 25  $\mu\text{m}$  or 1 mil and is then annealed and lapped and cleaned to form a planar surface for building the chip 22. The term "lapping" is used in the present invention to describe at least somewhat abrasive rubbing or polishing of a surface that removes irregularities and provides a smooth, planar surface, while generally reducing the thickness of a layer a predictable amount. Forming such planar surfaces on layers that may contain various portions of discrete elements is important for accurate construction of the chip 22 from a number of layers.

Instead of employing a release layer for removal of the chips 22 from the wafer, the wafer may be selectively etched to free the chips. For example, a silicon (Si) wafer may be sputtered with an alumina layer that is to become a side of the chip 22 facing away from a disk. That alumina ( $\text{Al}_2\text{O}_3$ ) layer is then chemically etched to form holes for a pair of gold interconnect buttons that provide electrical leads between the transducer 20 and the disk drive. A reactive ion etch (RIE) is then performed with  $\text{CF}_4/\text{O}_2$  to extend the

holes into the silicon wafer, after which a seed layer is sputtered on the alumina and through the holes. A photoresist mask is then formed surrounding and having a greater diameter than each hole, and then a layer of gold is electroplated to a thickness that substantially exceeds the alumina thickness, so that the gold extends through the holes and protrudes from each side. After the remaining layers of the chips 22 are formed, as will be described in detail below, the wafer is selectively etched, leaving the thin film chips. Optionally, prior to etching most of the wafer can be ground away, leaving about 2 mils of silicon attached to the alumina layer and gold buttons. While the chips 22 are protected with a photoresist or other covering, the remaining Si wafer is removed with another RIE etch, thereby freeing the chips.

Returning in Fig. 7 to the process flow that employs a release layer, atop the polished CuRL 114 an adhesion layer 115 of titanium (Ti) is formed, on which a layer 116 of alumina is deposited, although other electrically insulative, amagnetic materials such as silicon dioxide ( $\text{Si O}_2$ ) may instead be employed for layer 116. The adhesion layer 115 keeps the CuRL 114 and alumina layer 116 from separating, like a double sided atomic sticky tape, for which materials other than Ti could alternatively be used, such as chromium (Cr) or nickel iron (NiFe). After lapping to leave about 4  $\mu\text{m}$  thickness and cleaning, the alumina layer 116 is etched to form an interconnect orifice 118, while other similar orifices are formed at this time for test pads, not shown. This etching is preferably accomplished with phosphoric acid ( $\text{H}_3\text{PO}_4$ ) through a Ti mask which has been sputtered onto the alumina surface and photolithographically patterned and etched. Ion beam etching (IBE) is then performed through the Ti mask in order to extend the orifice

118 partially into the CuRL 114, although the test pad orifices are covered at this time so as to avoid their extension. A gold (Au) button 120 is then electroplated in an area overlapping and filling the orifice 118 and the test pad orifices adjoining the CuRL 114, the button 120 having a vertical thickness near its center of about 15  $\mu\text{m}$ , and spreading  
5 laterally and longitudinally a significant extent. To ensure that the button does not spread too far, a photoresist mask can optionally be formed atop the alumina 116 to define a border around the button 120. Another alumina layer 122 is then deposited, and then lapping is performed to the extent of dashed line 125, leaving the gold button 120 anchored to the alumina 116 and forming a flat surface along line 125, upon which  
10 additional layers of the transducer are to be formed.

When CuRL 114 is later removed to release a finished or nearly finished chip 22, a protrusion 127 of the gold button 120 beyond the alumina layer 116 will afford a conductive path to the transducer 20 for a suspension or support, while another similar conductive button, not shown, offers a return path for electrical current and potential.  
15 These buttons offer structural as well as electrical connections between the chip 22 and the suspension that allow appreciable torque about the lateral and longitudinal directions, which is beneficial in allowing the chip to conform to the spinning disk surface. A third gold button, also not shown, is formed at a location spaced apart from the other buttons to provide another mechanical connection for the chip. The lateral and longitudinal  
20 extension of the button 120, and the similar extension of other buttons that are not shown, in what will become the interior of the chip 22 anchors those connective buttons to the chip.

Referring now to Fig. 8, atop the planarized conductive button 120 a 2500 Å thick layer of Ti is sputtered, which is then patterned using a photoresist mask and ion beam etched to remove unwanted Ti, forming an anti-seepage layer (ASL) 130 which extends laterally and longitudinally beyond the button 120. The IBE also forms target patterns of Ti, not shown, near the perimeter of the wafer for alignment of later steps in the fabrication process. The ASL has been patterned to leave an opening adjoining a middle of the button 120, which is now plated with a copper layer to form an interconnect stud 133. Optionally, a seed layer of Ti/Cu and photoresist plate through mask may first be formed in order to ensure uniform plating of the copper layer, after which the photoresist is removed and then the exposed Ti/Cu seed layer is removed by IBE. An approximately 9 μm thick alumina isolation layer 135 is then deposited and then lapped flat and cleaned to leave a flat surface including an exposed top of the interconnect stud 133.

Fig. 9 shows the formation of the top yoke 64 on the alumina isolation layer 135, beginning with the deposit of an electroplating seed layer 138 to a thickness of about 1000 Å. The seed layer 138 is then examined for roughness with a laser surface profiler, as it is important for the formation of the top yoke 64 that roughness of the isolation layer 135 and adjoining seed layer 138 be minimized, in order to reduce noise and increase the efficiency of the top yoke.

As shown in Fig. 10, the area for the top yoke 64 is then defined by window frame plating, including lithographically forming a resist border 141 of the top yoke on the seed layer 138. The top yoke 64 is then electroplated with NiFe, along with an uncovered area 142 of the seed layer 138 outside the border 141. A laterally directed magnetic field is

applied during the electroplating to create magnetic anisotropy in the NiFe yoke 64 having an easy axis of magnetization along the direction of the applied magnetic field, and thereby improve the magnetic characteristics of the top yoke 64. The photoresist border 141 is then removed, and the seed layer 138 that had been covered by that border

5 141 is thereafter removed by IBE, which also removes a small fraction of the electroplated yoke 64 and outside area 142. Another photoresist mask, not shown, is then formed covering the yoke 64 and extending over a portion of the exposed area which had formerly contained the seed layer 138 that was protected from plating by border 141. The electroplated area 142 not covered with the photoresist mask is then etched away and then

10 the mask removed to leave yoke 64. Window frame plating is employed repeatedly in the current invention to form magnetically permeable elements, which typically involve electroplating NiFe using fairly uniform current densities onto seed layers such as layer 138. The top yoke 64 is preferably formed of "permalloy", which is a NiFe alloy composed of about 80% nickel and 20% iron, by weight, although many other magnetic

15 materials can be used. The top yoke 64 is then examined with energy dispersive X-rays (EDX) to determine the atomic composition of that yoke.

Referring again to Fig. 9, atop the seed layer 138 separate from the top yoke 64 another layer of copper is then plated through a different photoresist pattern exposing stud 133 to form a conductive up lead 140 while the top yoke 64 is covered with

20 photoresist. After removal of the photoresist, an ion beam etch is then performed to remove the seed layer 139 disposed between the top yoke 64 and the up lead 140. A wet "Phillips etch" with dilute hydrogen sulfide ( $\text{H}_2\text{SO}_4$ ) and hydrogen peroxide ( $\text{H}_2\text{O}_2$ ) then

removes any remaining NiFe not protected with photoresist. In an alternative process, not shown, the seed layer for the up lead 140 can be formed of Ti/Cu in a separate step from the seed layer for the top yoke 64 rather than being simultaneously formed of the NiFe or MoNiFe seed layer used to plate that yoke. Another alumina layer 137 is formed  
5 and lapped to expose the up lead 140 and the top yoke 64. A seed layer 139 of nickel iron (NiFe) or molybdenum nickel iron (MoNiFe) is formed on the top yoke 64, the up lead 140 and the alumina layer 137. A photoresist layer, not shown, is then patterned to leave exposed portions of the top yoke 64 for electroplating a pair of magnetic return studs, of which return stud 62 is shown. The return stud 62 is formed by electroplating  
10 through a photoresist pattern, the return stud then being examined by EDX to ensure appropriate atomic composition. Another photoresist layer is then patterned that leaves exposed two areas of the up lead 140 for electroplating a pair of copper studs. This pair of studs comprises a center tap stud 144, which is formed on the up lead 140 adjacent to the top yoke 64, while a test stud, not shown in this figure, is formed for testing purposes.  
15 Another layer of alumina 148 is then deposited, which is then lapped flat and cleaned to expose the magnetic return stud 62, center tap stud 144 and the test stud, not shown in this figure.

In Fig. 11, similar process steps are employed to form a first coil layer atop the alumina layer 148 and center tap stud 144, and to extend the magnetic return stud 62. To  
20 form the coil layer and in other situations for which the formation of high quality magnetic material is not necessary, a process termed "through plating" is typically employed rather than window frame plating. The process of through plating differs from

window frame plating primarily by exposing via a photoresist mask and electroplating only those areas in which permanent elements are to remain, whereas window frame plating also exposes and plates additional areas, which later need to be removed.

A seed layer 150 of NiFe or MoNiFe is deposited and then coated with a photoresist layer, not shown, which is photolithographically patterned and selectively removed in areas to allow Cu electroplating of the coil section 96, which is atop the center tap stud 144, along with coil sections 152, 153, 155 and an array of other coils sections, not shown in this figure. After Cu electroplating, the layer of photoresist that had allowed exposure of the coil sections 96, 152, 153 and 155 is removed and another photoresist layer is deposited and selectively developed to leave exposed a portion of the seed layer 150 above the magnetic stud 62. Another layer of the magnetic stud 62 is then formed by window frame plating of permalloy on the exposed (Mo)NiFe seed layer 150. Another layer of photoresist is then formed, leaving an area above the coil section 155 exposed for plating. A copper interconnect stud 158 is then electroplated on the top of section 155 to provide an electrical connection between the coil layer shown in Figs. 10 and 11 and the second coil section, not shown in these figures. After the photoresist has been removed, the seed layer 150 exposed between the magnetic studs 61 and 62 and the various coil sections including sections 96, 152, 153 and 155 is removed by IBE or similar process to electrically disconnect the various studs and sections. Another layer of alumina 160 is then sputter deposited and lapped to form a flat surface exposing interconnect stud 158 and magnetic studs 61 and 62, the surface then being cleaned to prepare for the formation of another similar coil layer along with another extension to



magnetic studs 61 and 62. The wafer may optionally be heated for a few hours at a few hundred degrees C° at about this point in the process, and additionally at later processing stages, to expel moisture or other contaminants from the layers.

The formation of the second and third layers of coil spirals and magnetic stud extensions proceeds along similar lines as that explained above with regard to the first coil layer, the detailed description of which is omitted for brevity. It should be noted that an array of approximately ten thousand transducers are formed simultaneously on a six inch diameter wafer, and in each of the layers of coil spirals a few positions of this array are devoted to test structures rather than working transducers.

In Fig. 12, a top view of the third layer of coil 84 shows that these coil sections are part of a coil spiral 156 that winds repeatedly around the magnetic return stud 62, while another coil spiral 157 winds in an opposite direction around magnetic stud 61, the spirals 156 and 157 connected at a crossover 82. As mentioned previously with reference to Fig. 3, these spirals are connected at sections 94 and 95 to the second layer of coil spirals, which are connected to the first layer of coil spirals, which are connected via interconnect studs 133 and gold buttons 120 to provide electrical contact with the drive system.

Between the third layer of coil spirals and the bottom yoke an electrical isolation layer 170 shown in Fig. 13 is formed of a layer of alumina. Note that extensions for the magnetic studs 61 and 62 are first formed, by the seeding, photolithography and electroplating process described earlier. Similarly, a pair of copper test leads are formed at this level and lead away from the coils to provide connections for a probe, not shown,

to test the transducer. After formation of the studs 61 and 62, the leads and the alumina layer 170, lapping and cleaning are performed so that the layer has an approximately 5  $\mu\text{m}$  thickness and a smooth, clean surface.

In Fig. 13, atop the smooth surfaced isolation layer 170, a pedestal 178 is formed  
5 in order to elevate a portion of the magnetic core, including the poletips 44. The pedestal 178 may be formed by a variety of methods of which a preferred example involving chemical etching will now be described. A silicon carbide (SiC) etch stop layer 180 having a thickness of about 4000 Å is first sputter deposited on the wafer in order to protect the alumina layer 170 during etching to form the pedestal 178, which is also  
10 formed of alumina. A layer of alumina 177 which is to form the pedestal 178 having a thickness of about 12  $\mu\text{m}$  is then sputtered, atop of which a stressed, high bias layer 179 of alumina about 0.5  $\mu\text{m}$  thick is optionally formed, which etches faster than the thick alumina layer 177. This etching is performed by first depositing a metal etch mask of MoNiFe to a thickness of about 500 Å, on top of which a layer of photoresist 185 is  
15 applied and patterned. Exposed areas of the MoNiFe are then removed and the resist is hardbaked for rigidity, leaving a rectangular area 182 protecting the top of the pedestal, a small side of this area 182 being shown in this cross-sectional view. The 12  $\mu\text{m}$  thick layer of alumina is then chemically etched with a solution of HF diluted to 15% by volume, although other chemical etchants may be alternatively employed, until the SiC  
20 layer 180 is exposed. Nearly completed etching of the pedestal 178 is shown in Fig. 13, which will result in a peaked pedestal having sides 188 that slope at an angle of 40° to 60° and are symmetrically disposed between the studs 61 and 62. The angle of the

pedestal sides 188 is important in controlling the magnetic separation and area of the bottom yoke adjacent to the poletips 44, which is important in optimizing the magnetic performance. Control of pedestal side 188 slope is important for achieving a desired thickness and stress of the plated NiFe bottom yoke for magnetic stability. The

5 photoresist 185 and metal mask 182 fall from the pedestal and are removed once the bias layer 179 has completely disintegrated. A reactive ion etch (RIE) preferably utilizing a  $\text{CF}_4/\text{O}_2$  plasma is then employed to remove the SiC etch stop layer 180, except for a portion of that layer disposed beneath the pedestal 178.

Referring now to Fig. 14, atop the studs 61 and 62, the alumina isolation layer 170

10 and the pedestal 178, a seed layer 190 of (Mo)NiFe is deposited to a thickness of about 1000 Å. A photoresist layer, not shown, is then patterned to leave exposed the seed layer 190 in the desired shape of the bottom yoke 60 (see Fig. 4), outlined by a "window frame" of photoresist with additional areas of the seed layer covered for the later formation of copper studs. An approximately 3 µm thick layer of permalloy is then

15 electroplated atop the seed layer 190 to form the bottom yoke 60, blanketing the peaked pedestal 178, after which the photoresist is stripped from the wafer. The thickness of the bottom yoke 60 is important to the saturation and overwrite performance of the transducer, as the yoke 60 is designed to saturate at a flux level slightly below that which would cause the poletips 44 to saturate, keeping the poletips from saturating and therefore

20 keeping the magnetic field at the poletips from broadening. Another layer of photoresist is now deposited and patterned to leave exposed areas of the seed layer 190 for forming copper studs having a thickness of about 14 µm, not shown, that are connected to the

copper test leads which are in turn connected to the coil 84, to allow wafer level testing of inductance and resistance of the coil. The photoresist is then removed, followed by IBE removal of the seed layer that is not covered by the yoke 60 or test studs, and then a wet etch removal of the permalloy left in the "field" outside the window frame, after which

5 the yoke and studs are again covered with photoresist, which is thereafter stripped. The wafer surface is then coated with a layer of alumina 195 that is thick enough (at least about 15  $\mu\text{m}$ ) to be nowhere lower than any of the protruding elements such as the pedestal 178 or copper test studs. The wafer is then lapped sufficiently to separate the yoke 60 by exposing the pedestal 178, obtaining the form shown in Fig. 14. The size of

10 the yoke 60 separation is carefully controlled to be approximately 3  $\mu\text{m}$  in this embodiment, as a smaller separation can lead to magnetic flux crossing between the yoke 60 rather than the gap 46, while a larger separation can constrict the flow of flux between the yoke and the poletips 44.

In Fig. 15 the formation of the poletips 44 atop the yoke 60 and pedestal 178

15 begins with the deposit of a seed layer 199 of NiFe, which is then masked, plated and etched by window frame plating to form a first pole layer 202 of permalloy or other magnetic material. A layer 205 of amagnetic material such as hydrogenated carbon ( $\text{HC}_x$ ), SiC or Si is then deposited, which will become the amagnetic gap 46 between the poles 44. Although the layer 205 of amagnetic material that forms the gap 46 is formed

20 on an essentially vertical side of the pole layer 202 that is at least several microns in height, a uniform thickness of amagnetic layer 205 is formed on the side of layer 202 adjoining the gap 46 by sputtering in a vacuum chamber while positioning the platform

holding the wafer on which the transducers are being formed such that the sputtered material impinges the gap side of the pole layer 202 as well as the top of that layer. This uniform formation on a vertical edge can be accomplished by rotating or transporting the wafer across the base of the sputtering chamber, or simply by positioning the wafer at a location at which the sputtering material has an angled approach. To avoid recession of the pole 44 material relative to the gap 46 during operation and, conversely, to avoid excessive wear of the gap 46 relative to the poles 44, it is desirable that the gap 46 material have a hardness similar to or slightly less than that of the poles 44. For this reason Si is a preferred material for layer 205. The layer 205 is then masked with a photoresist layer 208 that has been patterned so that etching with IBE along mask edge 210 leaves the gap 46 above the pedestal, but removes the portion of the silicon layer that had been covering a portion of the yoke 60. The dimensions of the gap 46 will set the magnetic resolution during communication between the transducer and the disk, the width of the gap 46 being uniform and typically between about 0.05  $\mu\text{m}$  and 0.4  $\mu\text{m}$ , and preferably about 0.26  $\mu\text{m}$  currently. In Fig. 16 the patterned photoresist layer 208 has been removed and a second pole layer 212 has been formed by window frame plating or sheet plating adjoining the gap 46 and atop silicon layer 205. The silicon layer 205 and the portion of the second pole layer that was plated on top of the first pole layer 202 are then removed by lapping to leave a planar surface composed of the first and second pole layers 202 and 212 and the gap 46.

Referring now to Fig. 17, a photoresist mask 215, shown also in a top view in Fig. 18, has been formed in the elongated hexagonal shape desired for the poletips 44 and gap

46, however, the mask 215 is larger than the eventual poletip area, to compensate for removal of a portion of the mask during etching. The etching is done by IBE with the ion beam directed at a preselected angle  $\alpha$  to the surface of the pole layers 202 and 212, while the wafer is rotated, in order to form vertical sides of the poletips 44, aside from a tapered skirt 213, shown in Fig. 19, of the poletips 44, the skirt 213 acting as an aid to the subsequent formation of the hard wear material 52 that will surround the poletips. The vertical sides of the poletips 44 allows operational wear of the poletips to occur without changing the magnetic read write characteristics of the head. On the other hand, the skirt 213 allows the wear material 52 that wraps around the poletips 44 to be formed without cracks or gaps which can occur, for example, in depositing DLC, preferably by plasma enhanced chemical vapor deposition (PECVD) onto a vertically etched pair of poletips 44. Although this tapered skirt 213 can be achieved by a variety of techniques, an angled, rotating IBE is preferred to exactly tailor the vertical poletips 44 with tapered skirts 213.

The photoresist mask 215 has an etch rate that is similar to that of the NiFe poletips 202 and 212, so that when the angle  $\alpha$  is approximately  $45^\circ$  the pole layer 212 and the mask 215 are etched a similar amount, as shown by dashed line 218. Pole layer 202, however, is partially shielded from the angled IBE by the mask 215, so that a portion 220 of layer 202 that is adjacent to the mask is not etched, while another portion is etched as shown by dashed line 222. As the wafer substrate is rotated, not shown, pole layer 212 will have a non-etched portion 225 adjacent to an opposite end of the elongated mask 215, as will areas 227 and 228 adjacent sides of the elongated mask. Since areas 227 and

228 are adjacent larger widths of the mask 215 than areas such as 220 and 225 and are thus more shielded and etch slower, the rotation of the wafer is preferably slower during periods when the IBE is angled along the elongated length of the mask (closest either to portion 220 or 225). The angle  $\alpha$  may be changed to further control the shaping of the poletips 44, for example to employ a greater angle such as about  $60^\circ$  toward the end of the IBE. This rotating, angled IBE is continued for an appropriate time to create a pair of poletips 44 having vertical sides with a tapered skirt 213 and a flat, elongated hexagonal top centered about the gap 46.

After electrical testing, the wafer carrying the transducer is ready for the formation of the support pads 28, 38 and 40, as shown in Fig. 19, which focuses on the MAP 28 for clarity. An adhesion layer 230 of Si is deposited to a thickness of about 500 Å atop the poletips 44 and alumina layer 195. A layer 233 of DLC is then sputtered onto the adhesion layer 230. An approximately 1500 Å thick layer 235 of NiFe is then deposited, which is then patterned by IBE with a lithographically defined photoresist mask 238 to leave, after IBE, a NiFe mask disposed over the DLC covered poletips 44 and over portions of the DLC layer at positions corresponding to the MIPS 38 and 40, not shown in this figure. The DLC layer 233 covered with the NiFe masks is then reactive ion etched with  $O_2$  plasma to leave projections of DLC that form the MAP 28 and MIPS 38 and 40. The MAP 28 and MIPS 38 and 40 are then lapped to expose the poletips 44. The MAP 28 and MIPS 38 and 40 are next protected with a photoresist which extends laterally and longitudinally beyond the edges of each pad, and then an RIE etch using  $CF_4/O_2$  removes the Si layer 230 not covered by the resist, leaving a flange of Si which

helps to position undercutting of the alumina layer 195 further from the MAP and MIPS, resulting in a stronger MAP and MIPS that are thicker closer to the disk-facing surface.

The chip 22 is then laser scribed to provide lateral and longitudinal separations from other chips that have been simultaneously formed on the wafer substrate 110. The above

5 described process has produced chips having the ability to write and read at densities approaching one gigabit per square inch, while variations to this basic chip design offer performance improvements.

As mentioned above, several techniques can be employed to increase the tendency of the chip to maintain contact with a disk, even at high speeds. Warping of the chip can  
10 be achieved by stressing the first-formed layer or several layers of the chip, so that upon release from the wafer substrate those layers, which are disposed away from the disk, expand, causing the disk-facing surface of the chip to be slightly concave. This concave disk-facing surface tends to form a negative air pressure region between the chip and the disk, holding the chip to the disk. Another means for creating such a negative air  
15 pressure region includes etching a recession in the disk-facing surface, preferably in a region spaced apart from the transduction section 48. Similar negative pressure effects can be achieved by tilting the chip so that the edge of the chip which first encounters a given portion of the spinning disk and adjoining air layer is spaced closer to the disk than the downstream edge of the chip. Typically the MIPS 38 and 40 are disposed upstream  
20 of the MAP 28, and so such tilting can be effected by tapering the MIPS so that they have an initial wear rate which is greater than that of the MAP, thus shortening the MIPS compared to the MAP. This difference in initial wear rate can be accomplished by



forming the MIPS with a smaller area of DLC layer 233 than layer 195, for example.

After the initial thinner portion of the MIPS has been worn away, either by lapping or by employment in a drive, the MIPS are designed to have a vertical wear rate equal to that of the MAP, maintaining the desired tilt of the chip. Similarly, one of the MIPS 38 or 40

5 which is to be positioned during operation further from the center of a disk than the other MIP, can be designed to have a tapered shape resulting in a faster initial wear rate so that when the chip is disposed near a rapidly spinning outer radius of the disk, a skew of the chip relative to the airflow causes the upstream corner of the chip to be tilted closer to the disk, holding the chip to the disk. This technique is especially useful in larger form factor  
10 disk drives, where the tendency to fly at an outer diameter of the disk is greater.

Means for performance improvement include increasing the permeance of the magnetic core, which may be accomplished by laminating the yokes, as shown in Fig. 20, including forming a thin amagnetic layer 265 between the formation of first and second magnetic layers 267 and 270, respectively, to construct a laminated bottom yoke 272.

15 Lamination of the magnetic core is believed to increase the magnetic flux-carrying capability of the core, particularly at high frequencies, by increasing the proportion of the core which carries magnetic flux. With changing magnetic fields, electrical eddy currents can occur in a skin layer of the conductive magnetic core material that in turn create magnetic fields in the core inward of the skin layer that counteract the desired magnetic  
20 fields. Division of the core into strips, layers or filaments increases the proportion of flux-carrying skin layer as compared to nullified inner core, increasing the overall permeance of the core. Division of the core to smaller sizes than necessary to remove the

nullified inner core can, however, reduce the overall flux-carrying capability of the core, as amagnetic spacer material begin to replace the flux carrying skin layer. An optimum thickness of the skin layer depends upon factors such as the conductivity and permeability of the core material, and is generally inversely proportional to the square root of the frequency, which may be on the order of 50 MHz, so that an optimum skin layer for the core of the preferred embodiment is on the order of 1  $\mu\text{m}$ .

Another way to improve performance, particularly during writing, involves employing a high magnetic saturation ( $B_s$ ) material such as cobalt zirconium niobium or FeAl(N) for a layer of the poletips 44 adjoining the gap 46, thus ensuring a high intensity magnetic flux adjacent to the gap for increased magnetic field gradients and high resolution writing. A high magnetic saturation ( $B_s$ ) or high moment material is generally defined, for the purpose of this application, as one that does not saturate at field strengths greater than 10,000 Gauss. One means for constructing a high  $B_s$  layer along a side of a poletip adjoining the gap is shown beginning in Fig. 20. After depositing and planarizing an alumina layer 275, a first pole section 277 of permalloy or other conventional magnetic material is formed by window frame plating, on the top and side of which is formed an approximately 1000 Å thick layer of a high moment material 280 (from the group mentioned above or other high  $B_s$  materials) by sputtering at an angle, as shown by arrows 281. A vertically directed IBE (normal to the wafer surface) is then performed to remove the essentially horizontal sections 282 of layer 280 disposed atop alumina layer 275 and pedestal 285, while most of an essentially vertical layer 288 of high  $B_s$  remains after the IBE.

In Fig. 21 an amagnetic gap 290 has been formed adjoining the film 288 of high  $B_s$  material 288 by the method described above, after which another layer 292 of high  $B_s$  material is sputtered at an angle to cover a side of the gap 290 as well as the top of the first pole section 277 and alumina layer 275. This high  $B_s$  layer 292 also serves as an electroplating layer for a second magnetic pole section 295, which may be formed of permalloy. After planarizing, not shown in this figure, to expose the gap 290, a high moment layer thus adjoins both sides of the gap, providing a much higher saturation field for writing as well as a harder or otherwise more durable structural material that maintains a sharply defined gap despite wear for continued high resolution. Alternatively, since a high moment material is needed for increasing the saturation level of flux adjacent to the gap for writing, and so for writing only needs to be formed adjoining a downstream side of the gap relative to the moving media, only the downstream poletip needs to be coated with the high moment material. This high moment coating may be formed by a similar process as employed to form the gap or the high moment layer 288, which were described above and will be omitted here for brevity.

As mentioned above, another means for increasing the efficiency of the transducer involves laminating some or all of the core, which may be employed in concert with the above described high moment material 280 adjoining the gap 46. This division of the core is accomplished in the present invention by forming each of the magnetic yokes in a pair of layers, the layers each having a thickness of about 1.5  $\mu\text{m}$  to 2.0  $\mu\text{m}$  and separated by an approximately 0.1  $\mu\text{m}$  thick amagnetic (preferably alumina) space, rather than the approximately 3  $\mu\text{m}$  thickness of solid yokes 55 and 64 described above. Similar

division is accomplished with the magnetic studs by forming a group of at least a few separated magnetic areas in each of the layers that are stacked to form the studs, rather than the solid magnetic studs 61 and 62 described above.

A top view of a layer including a pair of laminated studs 296 is shown in Fig. 22

5 to include a number of magnetic slats 297 each having a width  $W$  of about  $3\text{ }\mu\text{m}$  and a length  $L$  of about  $10\text{ }\mu\text{m}$ , the slats being separated by amagnetic material similar in dimensions to the slats, so that the overall width  $A$  of each stud 296 is about  $31\text{ }\mu\text{m}$  and the overall length  $B$  of the studs is about  $25\text{ }\mu\text{m}$ . The slats 296 may be formed of permalloy or other magnetic material, and are separated by approximately  $3\text{ }\mu\text{m}$  of

10 hardbaked photoresist. A series of generally identical stud layers is stacked to form the pair of complete studs that connect the laminated yokes or, as discussed below, a single laminated stud layer may connect the yokes. Fig. 23 shows an alternative construction of a layer of magnetic studs 298 utilizing strips 299 of magnetic material separated by hardbaked, amagnetic photoresist spacers. The overall dimensions  $A$  and  $B$  of each stud

15 298 in the layer are approximately  $31\text{ }\mu\text{m}$  and  $20\text{ }\mu\text{m}$ , respectively. Each strip 299 has a length of about  $31\text{ }\mu\text{m}$  and a width of about  $4\text{ }\mu\text{m}$ , and is separated from an adjacent strip 299 by about  $4\text{ }\mu\text{m}$  of resist.

Beginning with Figs. 24 and 25, the construction of an alternative and preferred embodiment of the current invention is shown which employs a curved, clamshell shaped

20 magnetic core having shorter magnetic studs formed by a single stud layer, the space needed for the several layers of inner coils being provided instead by curving of the top and bottom yokes. The construction of this embodiment of the transducer proceeds

essentially as described before except for the formation of the clamshell shaped core, which begins with the formation, atop the alumina isolation layer 135, of an etch stop layer 300 of SiC. The etch stop 300 is pierced by an interconnect stud 303, and has an alumina layer 305 formed thereon. The insulative, amagnetic layer 305 is masked with a photoresist patterned to expose areas at which the core and coils are to be formed, so that after essentially isotropic etching with dilute HF (similar to that employed to create the pedestal beneath the poles) a pair of plateaus 308 having sloping sides remains above the etch stop layer 300, separated by a recessed area 310 at which the etch stop layer 300 is exposed. The plateaus 308 and exposed portions of etch stop layer 300 (many thousand such plateaus 308 may be arrayed on a single wafer) are then sputtered with MoNiFe to form a first electroplating seed layer 313 about 1000 Å to 1500 Å thick. A first magnetic layer 315 of yoke 303 is then formed by sheet electroplating to a thickness of between 1 μm and 2 μm, and is then defined by ion beam milling. A thin (about 1000 Å thick) amagnetic layer 320 of alumina is then deposited, and a second MoNiFe seed layer 322 is then sputtered, after which a second magnetic layer 327 is formed by sheet electroplating and ion beam milling to be positioned atop amagnetic layer 307 and to have an area slightly less than that of first magnetic layer 315. The result is a yoke 330 having a flat, recessed middle surface 331 between a pair of raised, flat end surfaces 333.

In order to provide a planar, insulative surface for the formation of the first coil layer, a first photoresist layer 336 is then deposited to a thickness equal to the height of the recessed surface 331 above the etch stop layer 300 (approximately 4 μm), and patterned to remove those portions of the resist overlaying the yoke 330 and most of the

plateaus 308. A via 338 is also formed in the first resist layer 366 for later connection of the interconnect stud 303 with the first coil layer. The wafer is then heated first to about 100° C to remove impurities, and then gradually raised in temperature, which causes the remaining photoresist to melt and flow into small spaces left by the patterning and causes  
5 sides of the via to slope. After baking at approximately 250° C for a period of about 5 hours, gradual cooling hardens the photoresist, resulting in a hardbaked condition that offers a hard, insulative layer 336 with a flat surface 331 and 340 for formation of the first coil layer.

Referring now to Fig. 26, a second photoresist layer 344 is deposited at this point  
10 to provide insulation between the yoke 303 and a first coil layer, and is then developed to remove portions of that layer 344 over the via 338 and the end surfaces 333. This patterned second resist layer 344 is heated and baked according to a similar process as that described above for the first resist layer 336 to achieve the hardbaked condition. An approximately 500 Å to 1000 Å seed layer 348 of NiFe is then sputtered on the hardbaked  
15 resist 344 and interconnect stud 303, after which is formed, by through plating, a first copper coil layer 350 and an interconnect lead 349 that connects that coil layer 350 and the interconnect stud 303. Although only a few windings of the first coil layer 350 are shown in this cross-sectional figure for clarity, coil layer 350 has a similar shape and number of windings as that pictured in Fig. 12 (although coil layer 350 does not cross  
20 over). Another via, not shown, is also fashioned at an opposite end of coil layer 350 to provide connection by another interconnect lead, also not shown, for completion of the electrical circuit. A pair of interconnect studs 355 are formed at this point above an inner

section of coil layer 350 while the remainder of the coil 350 is covered with photoresist, only one of the studs 355 being shown in this figure.

An alumina layer 360 is then formed on and about the first coil layer 350, the alumina layer and interconnect studs 355 then being lapped and cleaned to provide a  
5 planar surface 363 for further processing. A second coil 366 is formed by through plating atop the alumina layer 360 and interconnect studs 355 on a seed layer, not shown.

Another interconnect 368 is formed on an outer coil section for electrical connection with the next coil layer. The magnetic strips 297 are then formed by electroplating, to form a single layer of laminated studs 296. An alumina isolation layer 370 is then formed on  
10 and about the studs 296 and coil 366, which is then lapped to expose the studs. An etch stop layer 373 of nonconductive SiC is then formed, followed by a third coil layer 377.

Portions of the etch stop layer 373 above the studs are removed, and another alumina layer 380 is formed on and about the third coil layer 377, which are then lapped flat.

Another etch stop layer 383 is then sputtered, on top of which a pedestal 385 is  
15 constructed as previously described. Most of the etch stop layer 383 that is not covered by the pedestal 385 is then removed by IBE. The pedestal 385, any exposed etch stop layer 383 and the exposed alumina layer 380 are then covered with photoresist which is patterned with openings above the studs 396. An isotropic etch is then performed through the above-stud openings which produces sloping sides 388 of alumina layer 380.

20 A first 390 and second 393 magnetic layer are then formed on top of the pedestal 385 and alumina layer 380 by window frame plating, with a thin amagnetic alumina layer 395 formed therebetween. The result is a terraced, laminated bottom yoke 399 and a

clamshell shaped, laminated magnetic core 400. The formation of poletips atop the pedestal 385 after lapping to separate the top yoke and the formation of hard material encompassing the poletips proceeds as previously described.

In Fig. 27, another embodiment is shown that utilizes a terraced bottom yoke to  
5 obviate the need for magnetic studs. The formation of this embodiment proceeds as described immediately above for the previous embodiment which has a single magnetic stud layer core 400, up to the step of forming a planarized surface 363 atop the top yoke 330, and so the description of this embodiment having a terraced bottom yoke and no magnetic studs will begin at that stage. Atop the planar surface 363 an etch stop layer  
10 404 of SiC is sputtered. A spiraling coil layer 408 is then formed by through plating on top of the etch stop layer 404. At this time portions of the etch stop layer 404 atop the raised end sections of top yoke 330 are removed by IBE, although the etch stop layer may alternatively be left intact. Much as before described, copper interconnects 410 are formed by double plating atop exposed outer sections of coil 408. Another alumina layer  
15 412 is now formed on and about the coil 408 and is lapped flat to expose the interconnect 410. Another etch stop layer 414 is now formed atop the flat alumina layer 412, and another layer of coils 418 is then formed atop that etch stop layer 414 and the interconnect which, as before, has been exposed by IBE. Another layer of alumina 420 is then formed on and around coils 418 and is lapped flat, after which an etch stop layer 422  
20 and pedestal 425 is formed, as previously described.

The etch stop covered alumina layers 418 and 412 are then etched in steps to form the terraced profile of those layers shown in this figure. This is achieved by first



removing by IBE that portion of etch stop 422 not covered by the pedestal 425, and then forming a photoresist pattern that has apertures over the raised ends 333 of the top yoke 330, in order to isotropically etch layer 418 to create sloping sides 428, with the etching being stopped by layer 414. Ion beam etching then removes that portion of layer 414 which is not covered by alumina layer 420, so that another photoresist layer can be patterned with apertures over ends 333 allowing isotropic etching of alumina layer 412 to create sloping sides 430. That etching is stopped by SiC layer 404 or, for the situation in which layer 404 has been removed to expose ends 333, the etching is stopped by those ends 333. A pair of magnetic layers 433 and 435 are then formed by window frame plating, with a thin (1000 Å) alumina layer 438 therebetween, in order to create a laminated bottom yoke 440. The wavy ribbon of laminated yoke 440 is now ready for the formation of a magnetic pole structure and wear pad, which proceeds as previously described and so will be omitted here for brevity.

In alternative embodiments, not shown, more or fewer coil layers may be formed, essentially by adding or deleting a step of forming a coil layer atop an etch stop layer. For instance, a transducer having only coil layers 350 and 408 may be formed by simply forming the pedestal 425 atop etch stop 414, instead of forming coil 418 on that layer 414. On the other hand, a transducer having four coil layers can be formed by constructing an additional coil layer on top of etch stop 422, and instead forming pedestal 425 on a later formed etch stop layer. One should also note that in other variations the magnetic core may include a wavy or curved bottom yoke while the top yoke is generally planar, although optionally laminated. Also, a curved bottom yoke may be formed on

alumina sides that have been sloped, without the employment of multiple etch stop layers, by isotropic etching of each coil-encasing alumina layer through photoresist apertures disposed over ends of the top yoke, with each successive aperture being smaller than the one through which etching of the previous alumina layer occurred.

5           As shown in Fig. 28, non-rectangular chip geometries may be formed by scribe lines 450, which form in this figure an array of T-shaped chips 455. The chips 455 each have one MAP 458 and two MIPS 460 disposed in a triangular pattern. After laser scribing is complete, poletips 44 are protected by a photoresist cover while the scribed chips 22 or 455 are exposed to an etchant such as nitric acid (NOH), which selectively  
10       dissolves CuRL layer 114 in order to release the formed chips 22 or 455 from the substrate 110.

Other chip geometries that accommodate a stable spacing of the MAP and MIPS are also possible and have advantages including allowing an increased number of chips per wafer and lowering the mass per chip. In particular, a trapezoidal chip 464, two of  
15       which are shown in Fig. 29, has proved to offer increased yield, lower mass and improved mechanical and dynamic performance. A side of the chips 464 facing away from the disk is shown to illustrate the gold interconnect buttons 120 and the leads 466 and 468 that connect those buttons with a pair of connected coils 470, so that current can flow through the coils via the buttons. Test pads 471 are positioned to allow connection, via the disk-  
20       facing side of the chip before formation of the final disk-facing isolation layer, not shown in this figure, with the coils 470 via leads 468. A pair of chips 464 is shown positioned as they would be on a wafer, which may hold ten thousand or more such chips. MAPs

472 are positioned near lateral extremities of each chip 464, while scribe lines 474 denote places at which the chips will be separated.

Fig. 30 shows a side of the T-shaped embodiment of the chip 255 that faces away from the disk and is attached to a gimbal structure 500 located near an end of a flexure beam 505. The attachment of the chip 255 to the gimbal 500 is made by soldering, ultra-sonic or thermo-compressive bonding of a conductive paste or metal alloy to the trio of gold buttons 120 on the chip. The flexure beam 505 is formed of a conductive material such as a stainless steel sheet that has been etched or micromachined to create separate conductive paths 510 and 512 that connect to the gold buttons 120 via the gimbal 500, in order to provide an electrical circuit for the chip 255 as well as tailored mechanical resilience and compliance. The flexure beam 505 also includes a layer of insulative damping material sandwiched between the conductive paths 510 and 512 and another hard but flexible layer, not shown. Also not shown in this figure is a shock absorbing cross bar that is spaced slightly apart from the beam 505 and that keeps the chip 255 from traveling more than a minute amount from the disk surface even under extreme shocks, transferring most of the energy from a shock away from the chip.

Fig. 31 shows a hard disk drive 520 in which the chip 255 operates in substantially continuous sliding contact with a rigid disk 525 on a magnetic recording surface 530 during communication. The beam 285 is connected to a compact, mass balanced rotary actuator 535 that moves the chip 255 between numerous concentric data tracks of the surface 305 while the disk 525 spins in a direction shown by arrow S. Although not shown, a similar chip slides on an opposite magnetic recording surface of

the disk 525, and typically several such disks each having a pair of chips sliding on opposite surfaces are included in a drive system. The drive 520 is designed to achieve substantially continuous sliding contact between the chip 255 and disk 525 at above 5000 RPM and linear velocities of above 10m/s. This high resolution, continuous contact communication is made possible in part by the extremely small size and non-flying characteristics of the chip, which is constructed entirely from a composite of thin films, as well as the flexible, low load beam 505 and gimbal 500, which provide damage free conformance between the chip and the disk, and the specific surface characteristics of the disk, which are prepared for such sliding, so that the resulting drive system achieves a synergistic combination optimized to yield a continuously sliding, high density hard disk drive system.

### Claims

1. A transducer for a rigid disk drive system, the transducer comprising  
a body having a mostly flat disk-facing surface and a protrusion extending  
from said surface,  
a magnetic loop contained in said body and extending further in a  
direction parallel to said surface than in a direction perpendicular to said surface, said  
loop ending with first and second magnetic pole structures disposed in said protrusion,  
said pole structures separated by an amagnetic gap and terminating substantially  
coextensively with said protrusion, and  
a conductive coil disposed in said body and inductively coupled to said  
loop, whereby providing an electrical current to said coil induces a magnetic field  
adjacent to said pole structures for writing a magnetic pattern to the disk.
2. The transducer of claim 1, and further comprising a pair of support legs extending  
from said surface a similar direction and extent as said protrusion.
3. The transducer of claim 1, wherein said disk-facing surface is formed primarily of  
at least one thin layer of materials.
4. The transducer of claim 1, wherein a portion of said loop has a magnetic  
saturation level that is less than that of said pole structures.

5. The transducer of claim 1, wherein at least one of said pole structures includes a high magnetic saturation material disposed adjacent to said gap.
6. The transducer of claim 1, wherein a cross-section of said loop is shaped generally like that of a closed pair of clamshells, with said pole structures projecting from one of said clamshells.
7. The transducer of claim 1, wherein said loop includes a plurality of elongated magnetically permeable members separated by an amagnetic layer, said members each having a thickness generally greater than that of said layer, whereby a permeance of said loop is increased.
8. The transducer of claim 1, wherein said slider has a conductive lead connected to said coil and piercing an insulative shell of said slider on a side opposite to said disk-facing surface.
9. The transducer of claim 1, wherein said pole structures have a pair of substantially parallel walls adjoining said gap that extend greater than four times as far in a vertical direction as a distance between said walls.

10. The transducer of claim 1, wherein said transducer is primarily composed of a plurality of adjoining material layers, with said gap having a shortest dimension oriented substantially parallel to most of said layers.
11. A transducer for a rigid disk drive system, the transducer comprising  
a body shaped like a table supported by three short legs,  
a conductive coil disposed in said body, and  
a magnetic core disposed in said body and inductively coupled to said coil,  
said core shaped as a loop having ends extending into a first of said legs and separated by an amagnetic gap, whereby a current flow in said coil produces a magnetic field adjacent to said first leg.
12. The transducer of claim 11, wherein said body is shaped like a T.
13. The transducer of claim 11, wherein said body has a generally trapezoidal shape.
14. The transducer of claim 11, wherein said core includes a plurality of elongated, closely spaced, magnetically permeable strips, such that a permeance of said core is increased.
15. The transducer of claim 11, wherein said ends terminate substantially coextensively with said first leg.

16. The transducer of claim 11, wherein said ends are encompassed by a durable amagnetic material.

17. The transducer of claim 11, wherein said ends have a pair of substantially parallel walls adjoining said gap that extend greater than four times as far in a vertical direction as said separation between said walls.

18. The transducer of claim 11, wherein a cross-section of said core is shaped generally like that of a closed pair of clamshells, with said ends projecting from one of said clamshells.

19. The transducer of claim 11, wherein said core includes a portion shaped generally like a serpentine ribbon adjoining said gap.

20. The transducer of claim 11, wherein said body is primarily made of a composite of thin layers of materials.

21. The transducer of claim 20, wherein said gap is one of said layers and is formed in an orientation generally orthogonal compared to most of said layers.



22. An information storage device comprising
- a rigid disk having a surface associated with a magnetic medium layer,
  - a slider having a disk-facing surface and a projection from said disk-facing surface disposed in a mostly sliding relationship with said disk surface, and
  - a transducer disposed in said slider and having a magnetic core and a conductive coil coupled to said core, said core forming a loop with closely spaced ends extending into said projection and terminating adjacent to said disk surface.
23. The device of claim 22, and further comprising a pair of spaced apart support legs projecting from said surface in a direction substantially similar to that of said projection.
24. The device of claim 22, wherein said core extends further in a direction parallel to said surface than in a direction perpendicular to said surface.
25. The device of claim 22, wherein a cross-section of said core is shaped generally like that of a closed pair of clamshells, with said ends projecting from one of said clamshells.
26. The device of claim 22, wherein said core includes a plurality of elongated, closely spaced magnetic strips along a substantial portion of said loop, whereby a magnetic permeance of said core is increased.

27. The device of claim 22, wherein said loop has a generally symmetric shape that extends furthest in a direction transverse to said projection.
28. The device of claim 22, wherein said slider has a conductive lead connected to said coil, piercing an insulative shell of said slider and protruding away from said disk.
29. The device of claim 22, wherein said ends have a pair of substantially parallel walls separated by an amagnetic gap, said walls extending more than four times as far in a direction substantially normal to said surface as said separation between said walls.
30. The device of claim 22, wherein said ends are separated by an amagnetic gap and include a high magnetic saturation material adjoining said gap.

31. A method for forming a transducer for a disk drive system, comprising the steps of:

- (a) providing a substrate having a surface,
- (b) forming a seed layer atop said surface,
- (c) forming a photoresist mask atop said seed layer,
- (d) electroplating said seed layer exposed by said mask, thereby forming a conductive pattern including a portion of at least one of an electrical circuit and a magnetic circuit,
- (e) forming a second insulative layer on and about said conductive pattern,
- (f) removing a portion of said second insulative layer, including forming a planar surface, and
- (g) repeating steps (b) through (f), including forming a magnetic pole layer in a final electroplating step.

32. The method of claim 31, wherein at least one said removing step includes exposing said conductive pattern.

33. The method of claim 31, further comprising forming a second magnetic pole layer in an electroplating step prior to said final electroplating step.

34. The method of claim 33, further comprising forming an amagnetic gap between said pole layers in a step performed between said magnetic pole layer forming steps.

35. The method of claim 34, further comprising forming a layer of high magnetic saturation material in a step performed between said magnetic pole layer forming steps.
36. The method of claim 31, further comprising removing a portion of said magnetic pole layers, including forming a pair of poletips with outside walls substantially perpendicular to said planar surface.
37. The method of claim 36, further comprising forming a protective casing of amagnetic material encompassing said poletips.
38. The method of claim 31, further comprising removing said transducer from said substrate surface.
39. The method of claim 31, further comprising  
forming an aperture in said first insulative layer, and  
forming a conductive lead extending through said aperture and anchored to said first insulative layer.
40. The method of claim 31, further comprising  
forming a curved surface, and  
forming a magnetic yoke on said curved surface, such that said yoke is a part of said magnetic circuit.

41. A method for forming a disk drive transducer comprising,
- providing a self-supporting substrate,
  - forming a first conductive layer atop said substrate,
  - forming a first insulative layer atop said first conductive layer, said insulative layer having a surface distal to said conductive layer,
  - forming an aperture piercing said first insulative layer and extending partially into said first conductive layer,
  - depositing a second conductive layer atop said first insulative layer, including forming a conductive lead in said aperture,
  - removing a first portion of said second conductive layer while leaving a second portion adjacent to said surface, and
  - forming a magnetic core and a conductive coil, with said coil inductively coupled to said core and connected to said lead.
42. The method of claim 41, and further comprising removing said first conductive layer, thereby releasing said first insulative layer and said lead from said substrate.

43. The method of claim 41, wherein forming said core includes  
forming a plurality of magnetic pole layers separated by an amagnetic gap  
disposed adjacent to said core and distal to said lead,  
removing a part of said pole layers and leaving a pair of poletips separated  
by said gap and connected to said core, including forming substantially vertical walls  
defining said poletips.
44. The method of claim 43, further comprising forming a tapered portion of said  
poletips extending from said walls adjacent to said core.
45. The method of claim 43, further comprising forming casing of hard, amorphous  
material encompassing said poletips.
46. The method of claim 41, wherein forming said core includes constructing a loop  
of magnetic material by stacking a series of layers each including patterned magnetic  
sections.
47. The method of claim 43, wherein said gap is formed after forming a first of said  
pole layers and before forming a second of said pole layers.
48. The method of claim 43, further comprising forming a layer of high magnetic  
saturation material between one of said pole layers and said gap.

49. The method of claim 41, wherein forming said core includes constructing a loop of magnetic material by forming a plurality of layers, each of said layers including a patterned magnetic section.
50. The method of claim 49, wherein forming a conductive coil includes constructing a plurality of conductive spirals that wind about said magnetic section.
51. A method for making an information storage drive system transducer comprising constructing, with a sequence of films, a loop of magnetic material and a coupled coil of conductive material such that said loop and said coil are embedded in insulative material and extend further along said layers than across said layers, and forming, adjacent to closely spaced ends of said loop, a first and second pole layer, with an amagnetic gap separating said pole layers and oriented generally orthogonal to said pole layers, said gap being formed between forming said first pole layer and forming said second pole layer.
52. The method of claim 51, wherein said gap is formed on a side of one of said pole layers.
53. The method of claim 51, further comprising removing a portion of said pole layers and thereby defining a pair of poletips separated by said gap and having a generally uniform cross-sectional shape.

54. The method of claim 53, further comprising forming a casing of hard, amorphous material encompassing said poletips, such that said poletips and said casing protrude from said transducer.

55. The method of claim 51, further comprising forming a layer of high magnetic saturation material adjoining said gap, said high saturation material being formed between forming at least one of said pole layers and forming said gap.

56. The method of claim 51, wherein forming said loop includes forming a plurality of layers of magnetic material and patterning said layers to form a plurality of magnetic strips.

57. The method of claim 51, wherein forming said loop includes forming a plurality of layers of magnetic material separated by a film of amagnetic material, and patterning said layers to form a plurality of closely spaced magnetic strips.

58. A method of forming an electromagnetic head for a hard disk drive comprising  
providing a self supporting substrate,  
forming on said substrate a sequence of thin films, including constructing  
an electromagnetic transducer, and  
removing said transducer from said substrate.

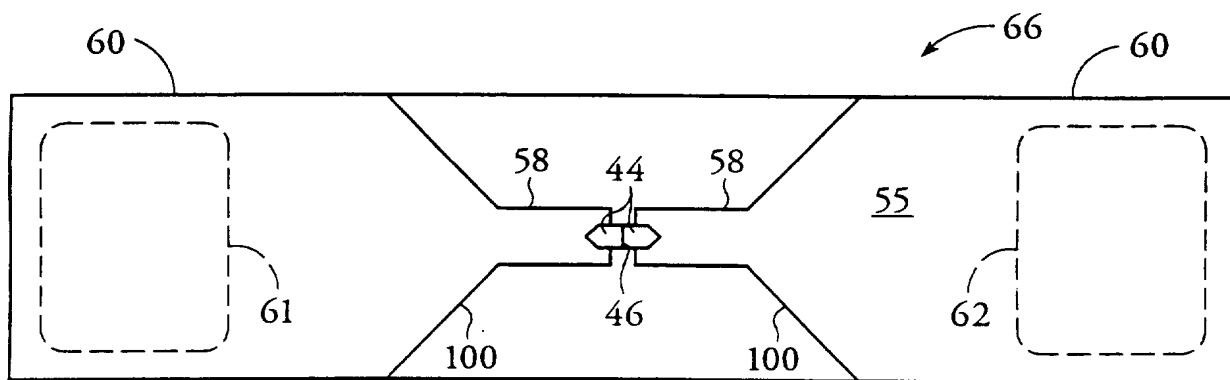
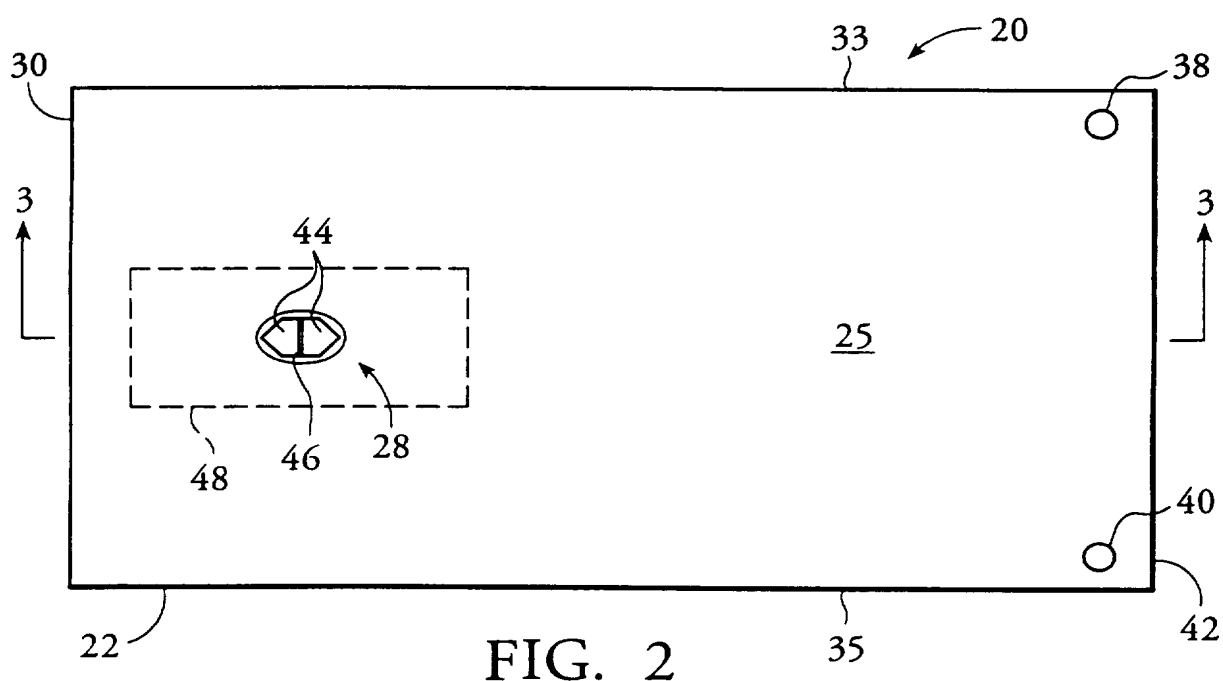
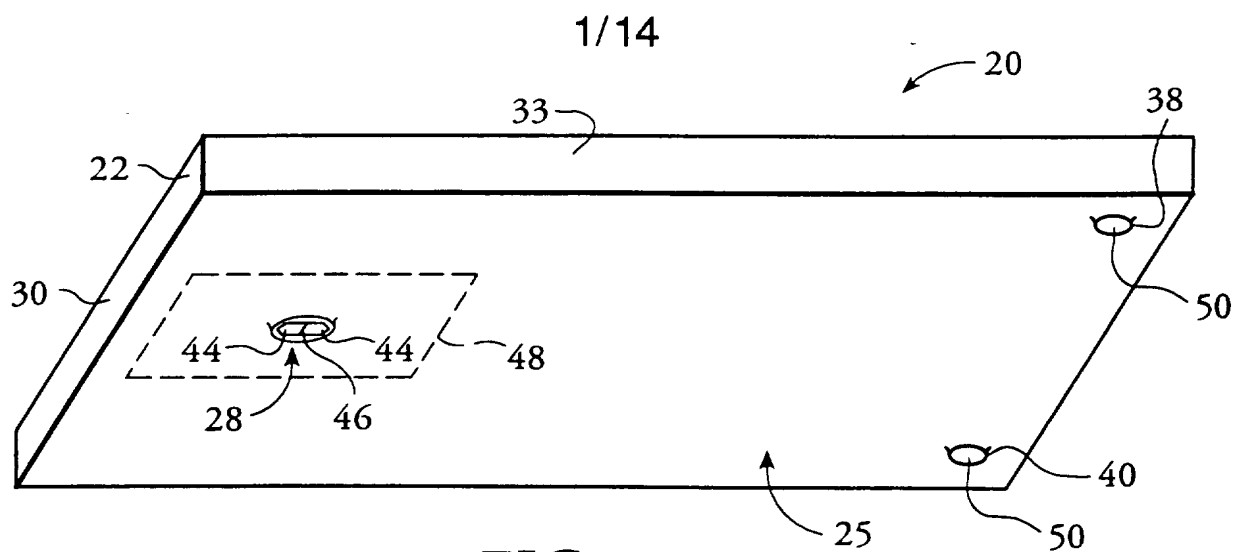


59. The method of claim 58, wherein removing said transducer from said substrate includes selectively etching said substrate, thereby removing substantially all of said substrate.

60. The method of claim 58, wherein forming on said substrate a sequence of thin films includes forming an etchable layer adjoining said substrate and wherein removing said transducer from said substrate includes selectively etching said layer, thereby removing substantially all of said substrate from said transducer.

61. The method of claim 58, wherein forming an electromagnetic transducer includes forming a pair of magnetic pole layers separated by an amagnetic gap, and removing most of said pole layers to leave a pair of magnetic poletips separated by said gap, such that said poletips have generally vertical sides with a tapered skirt near a bottom of said sides.

62. The method of claim 61, further comprising encasing said poltetips with a hard, durable material, and exposing said poletips and said gap.



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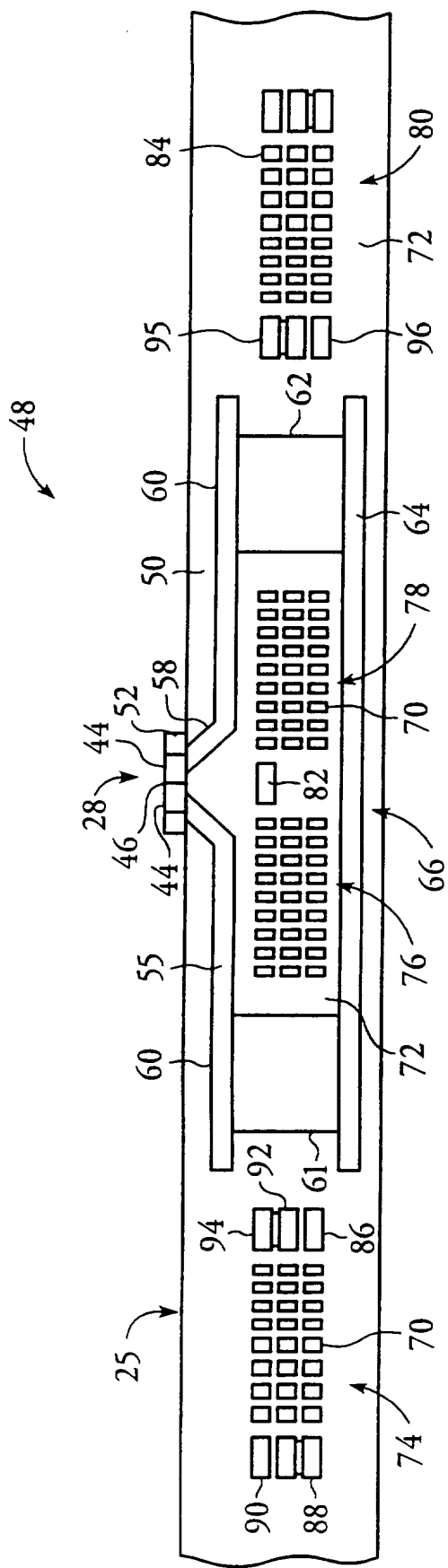


FIG. 3

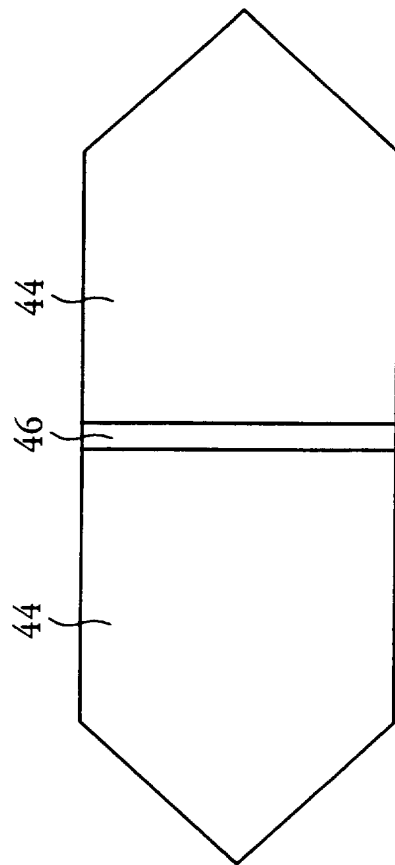


FIG. 5

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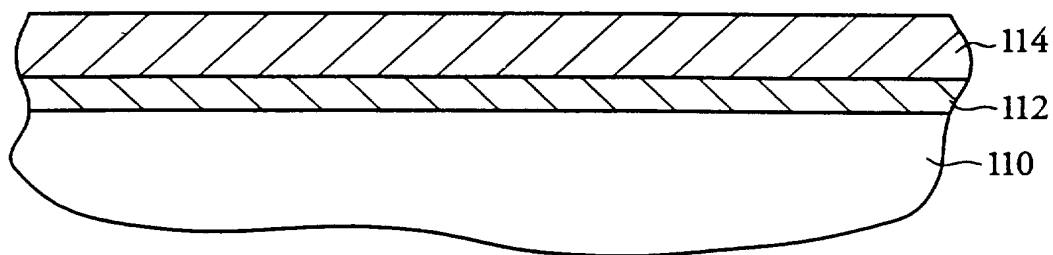


FIG. 6

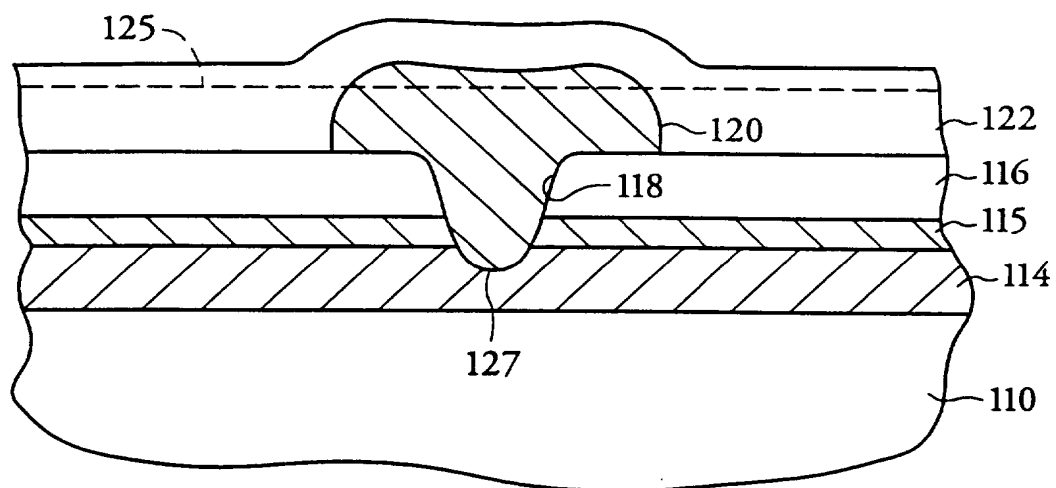


FIG. 7

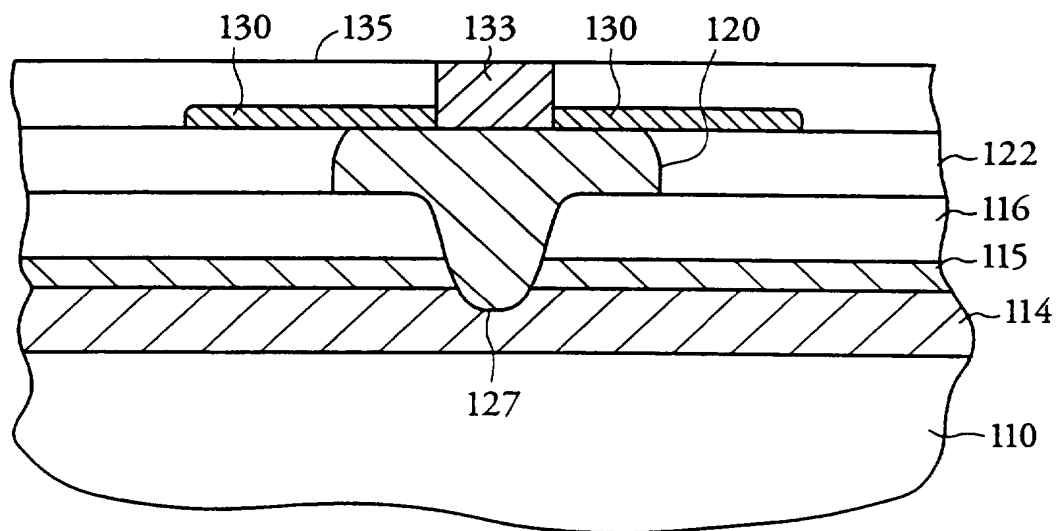


FIG. 8

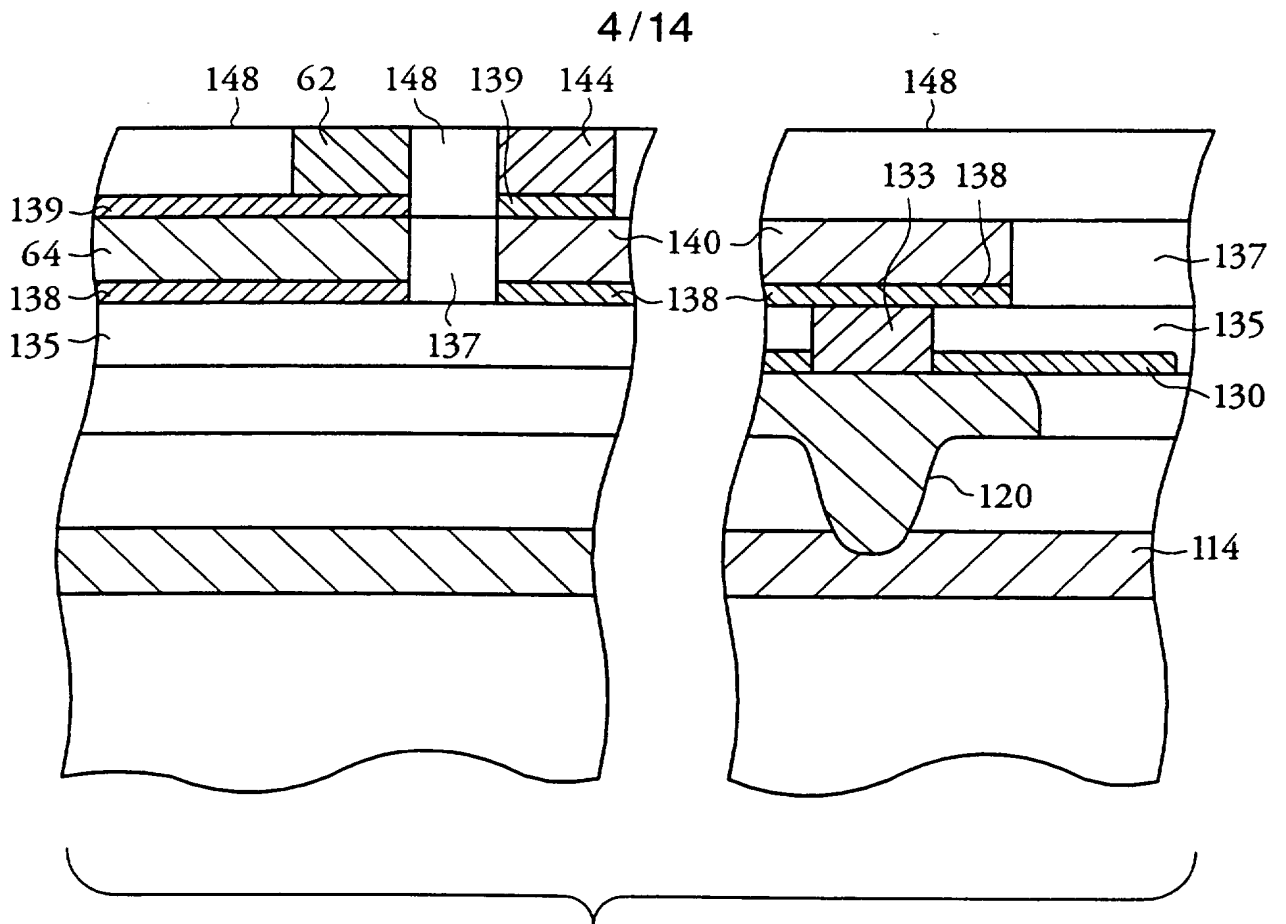


FIG. 9

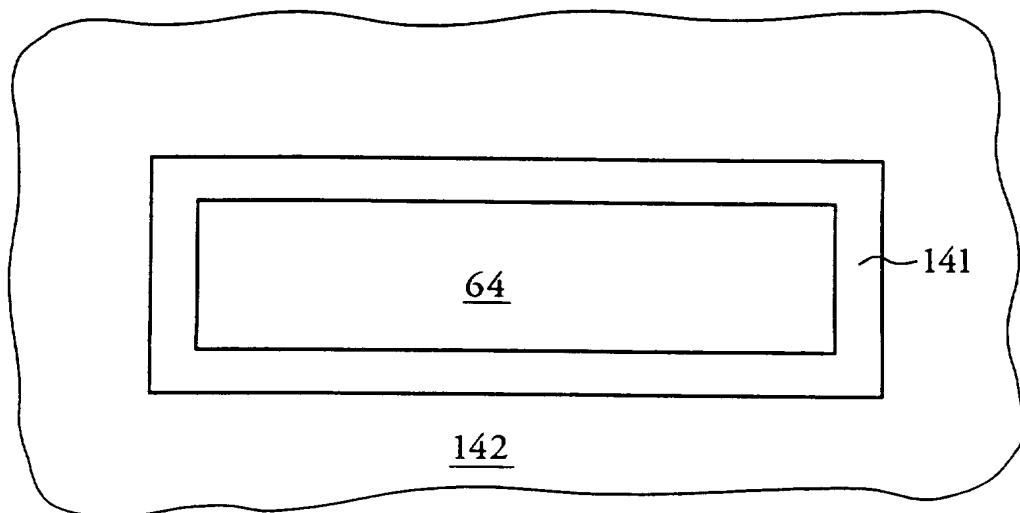


FIG. 10

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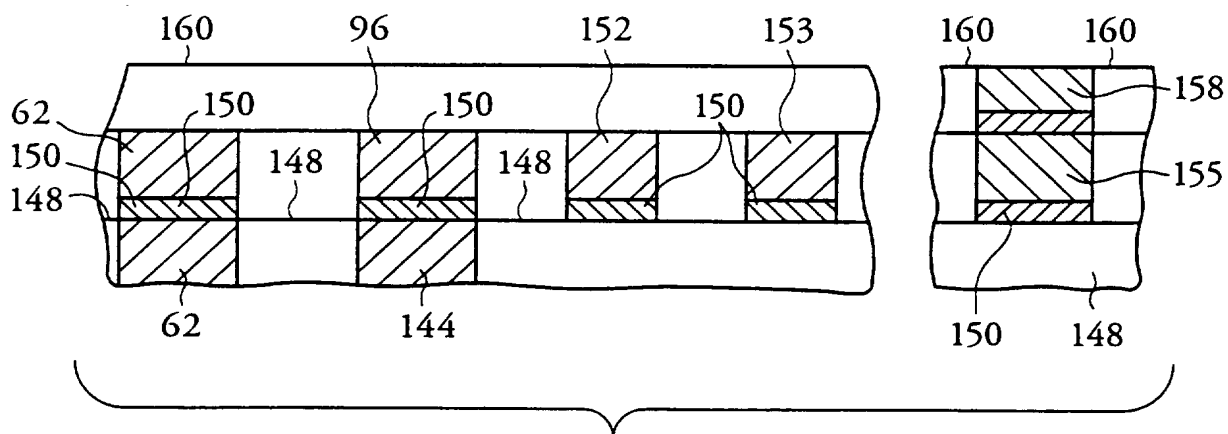


FIG. 11

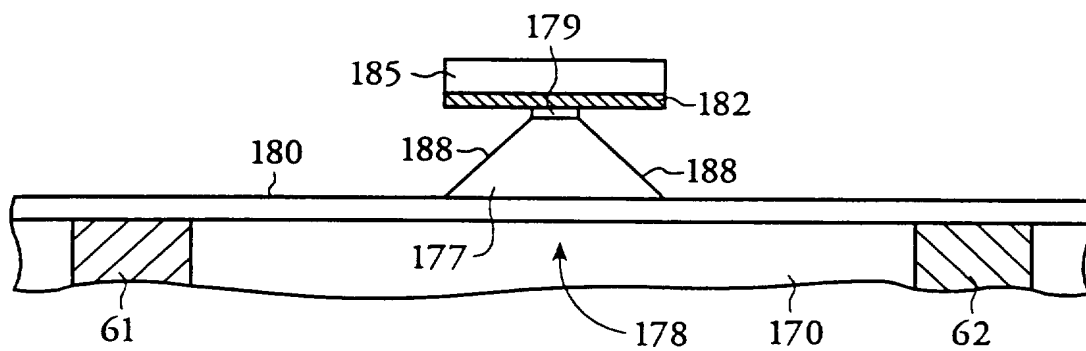


FIG. 13

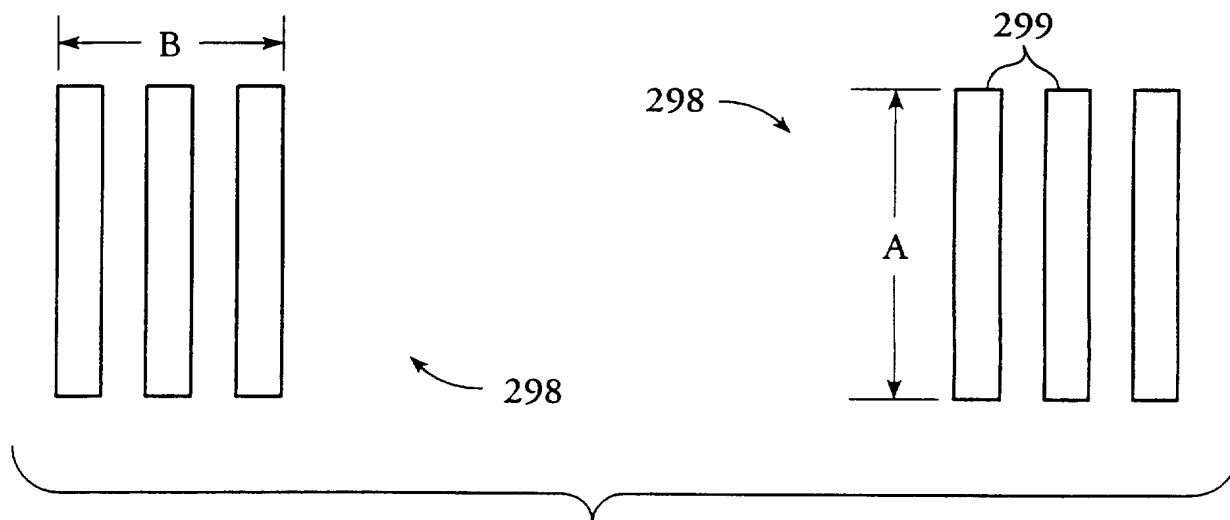


FIG. 23

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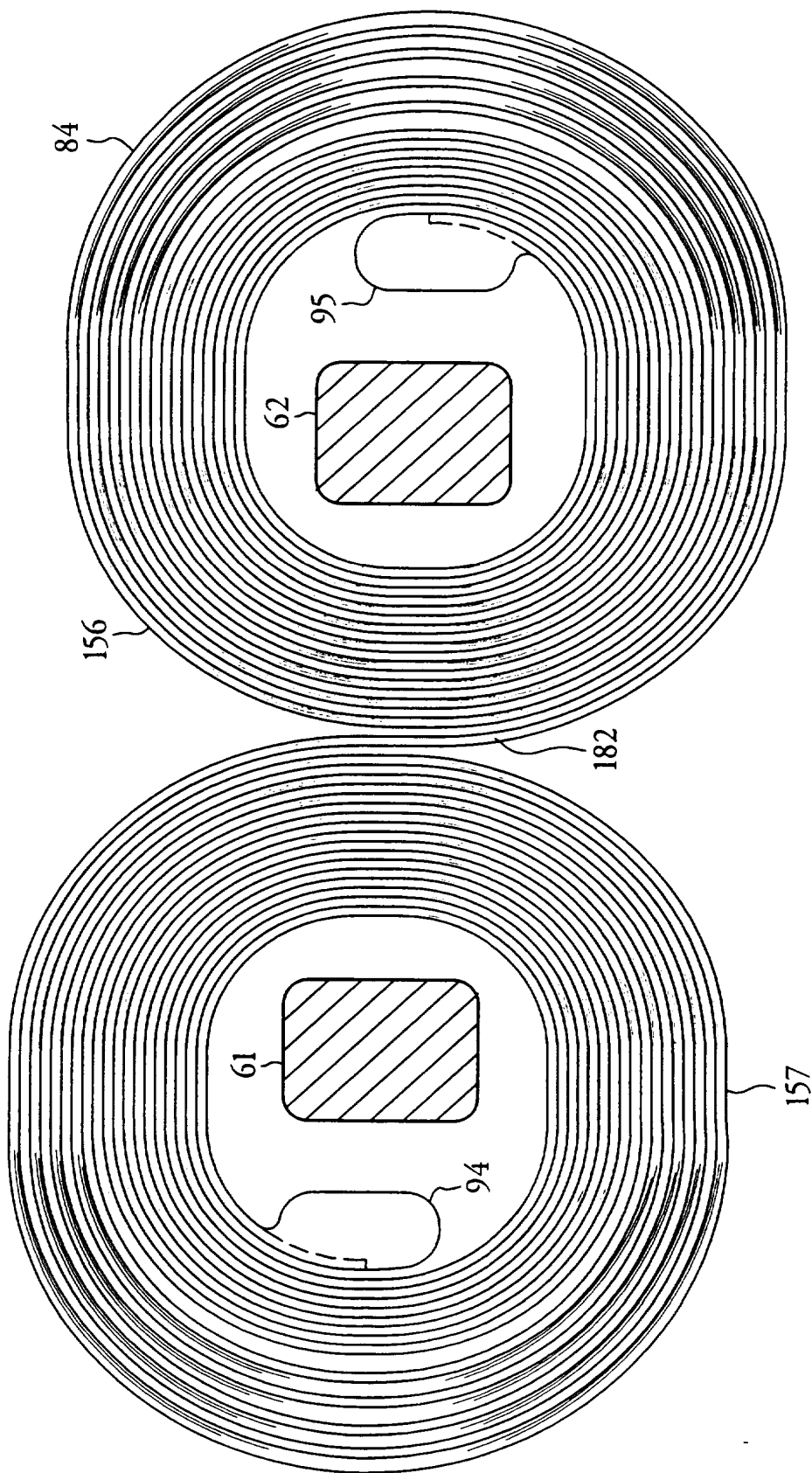


FIG. 12

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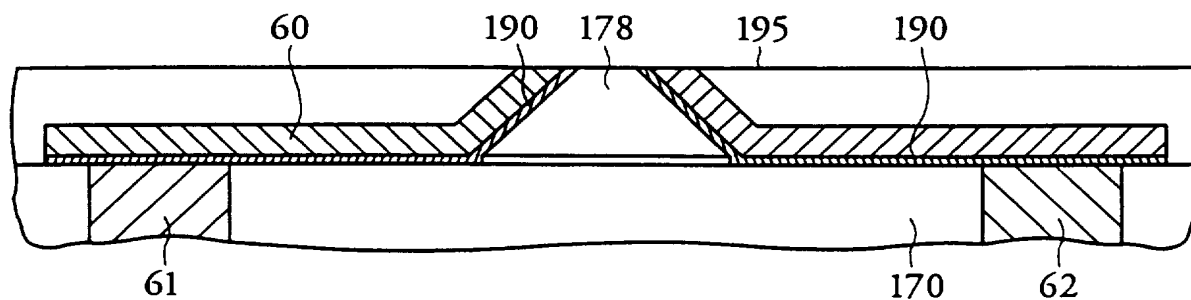


FIG. 14

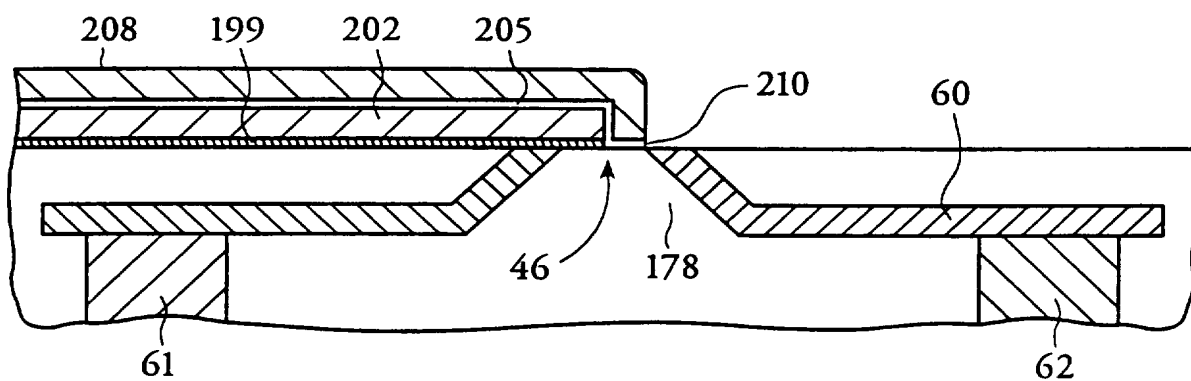


FIG. 15

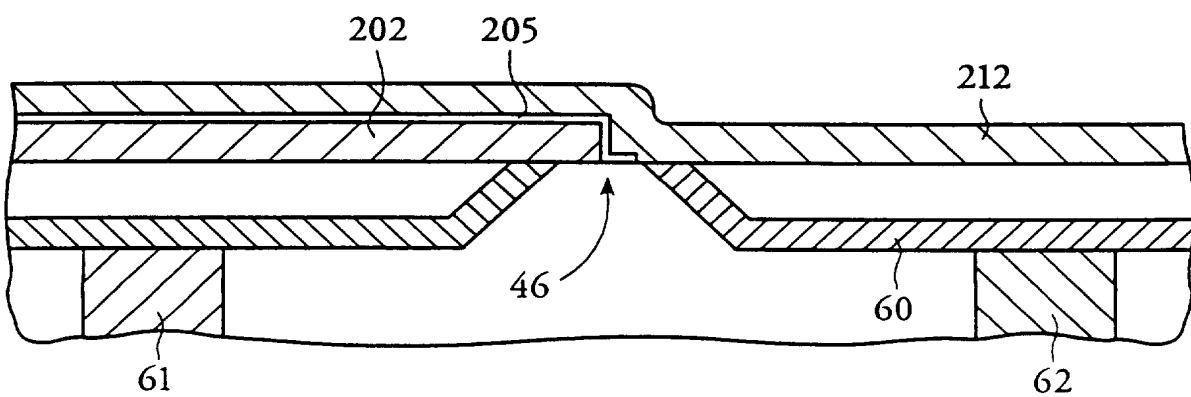


FIG. 16



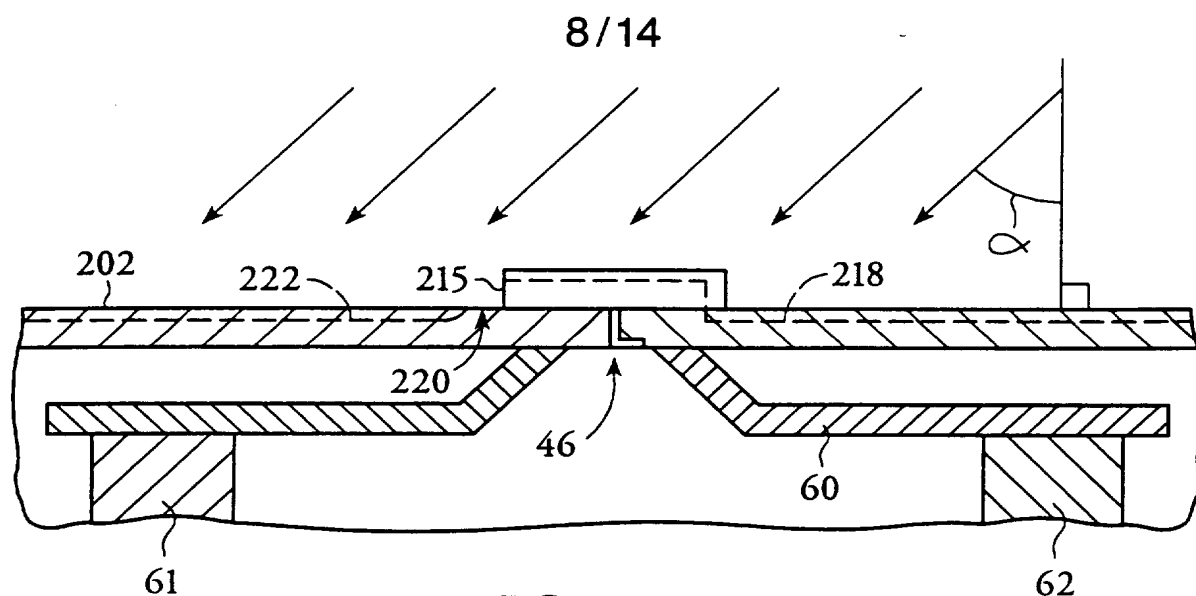


FIG. 17

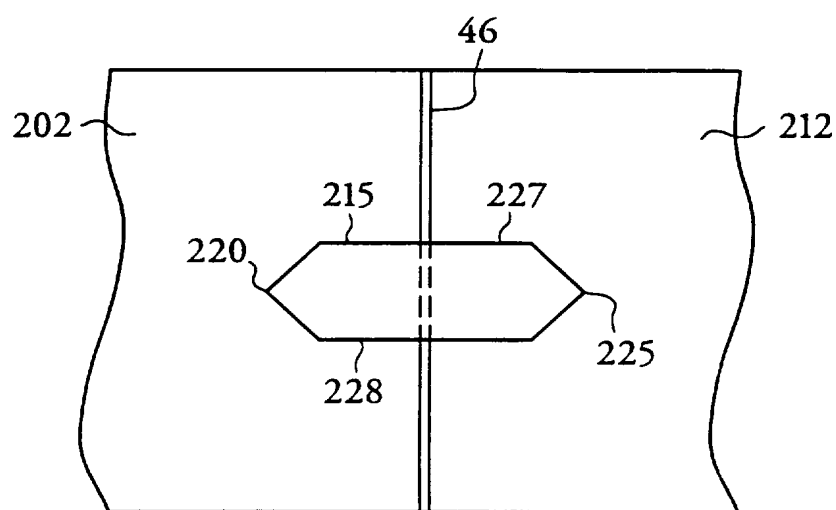


FIG. 18

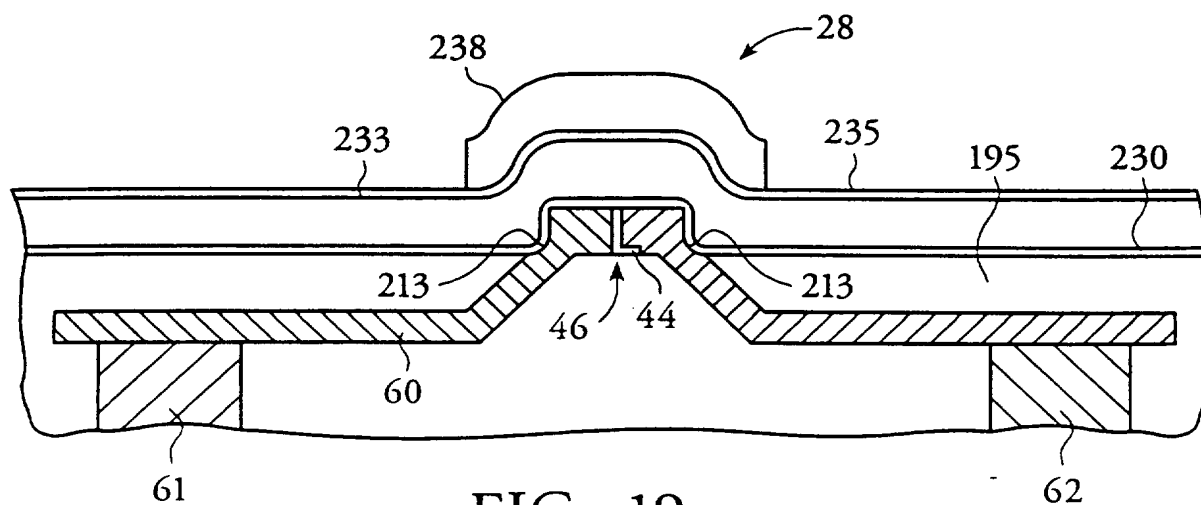
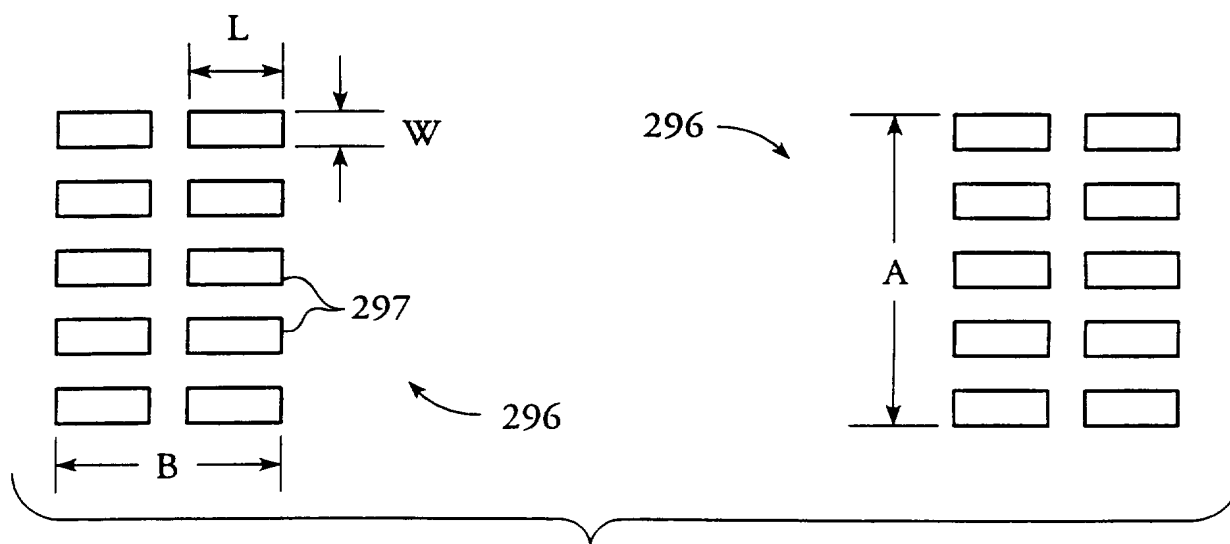
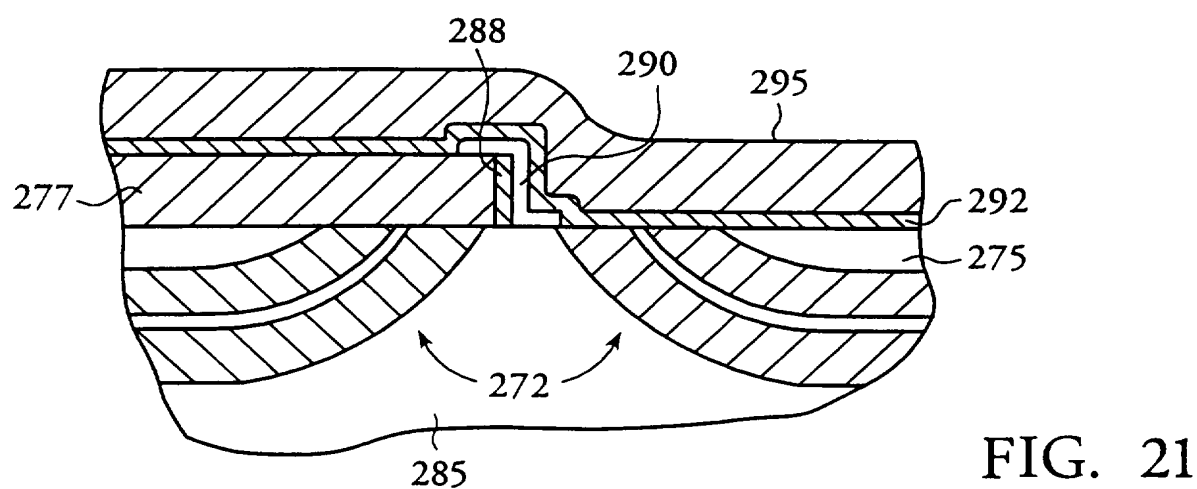
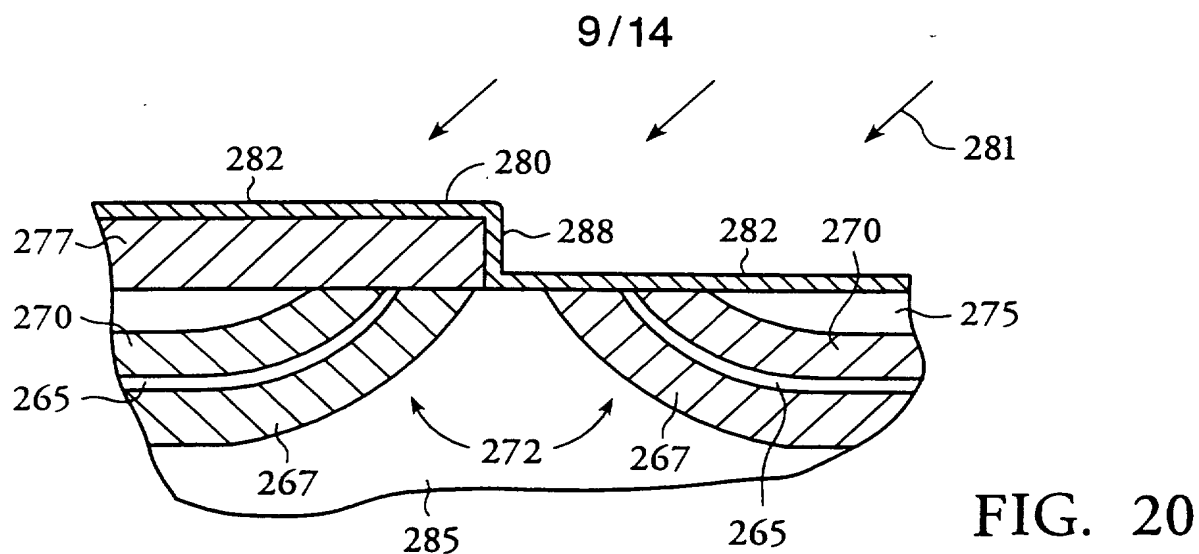


FIG. 19



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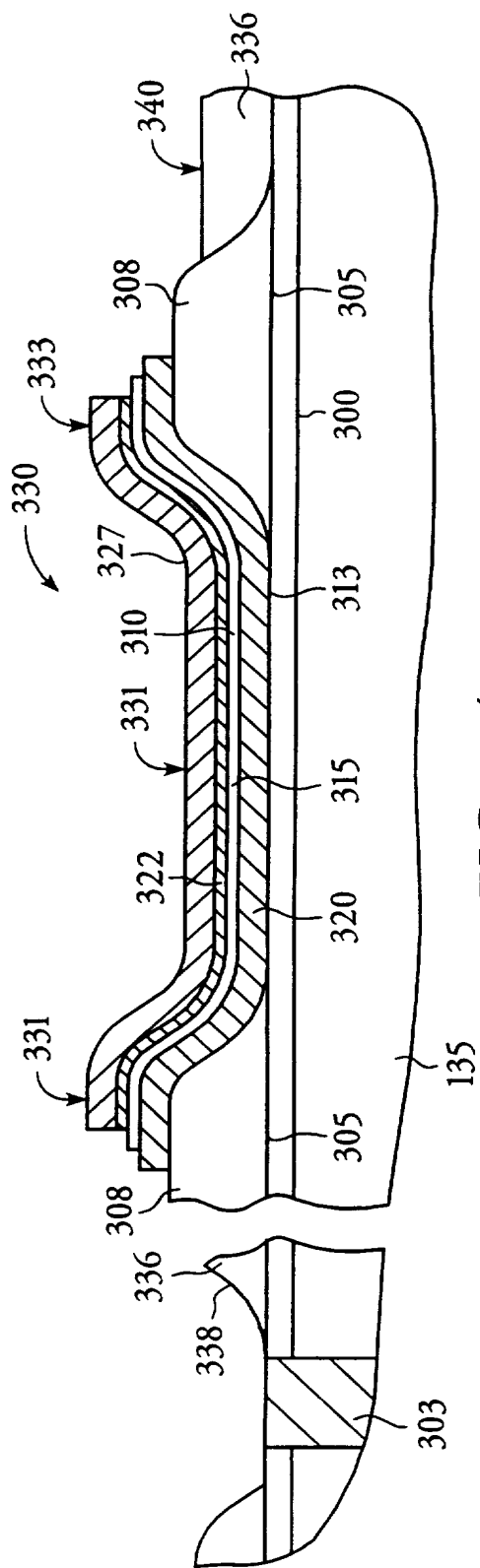


FIG. 24

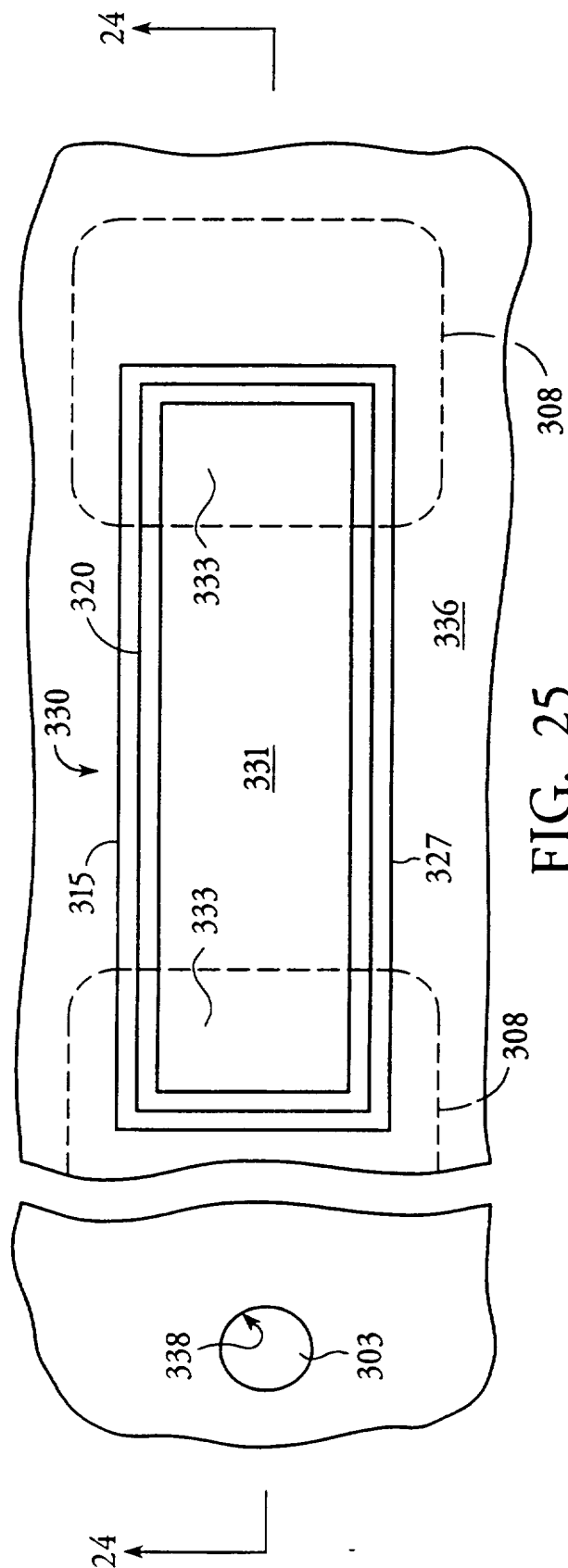


FIG. 25

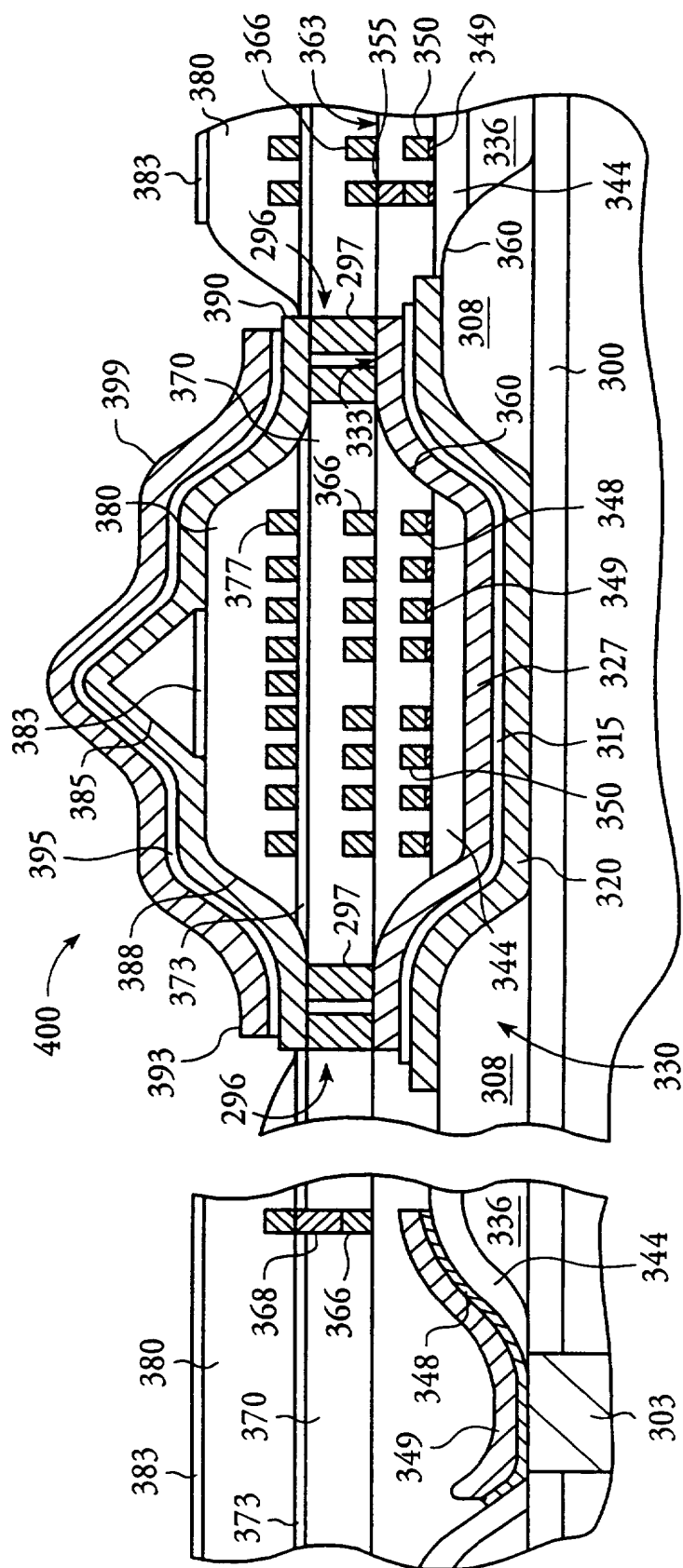


FIG. 26

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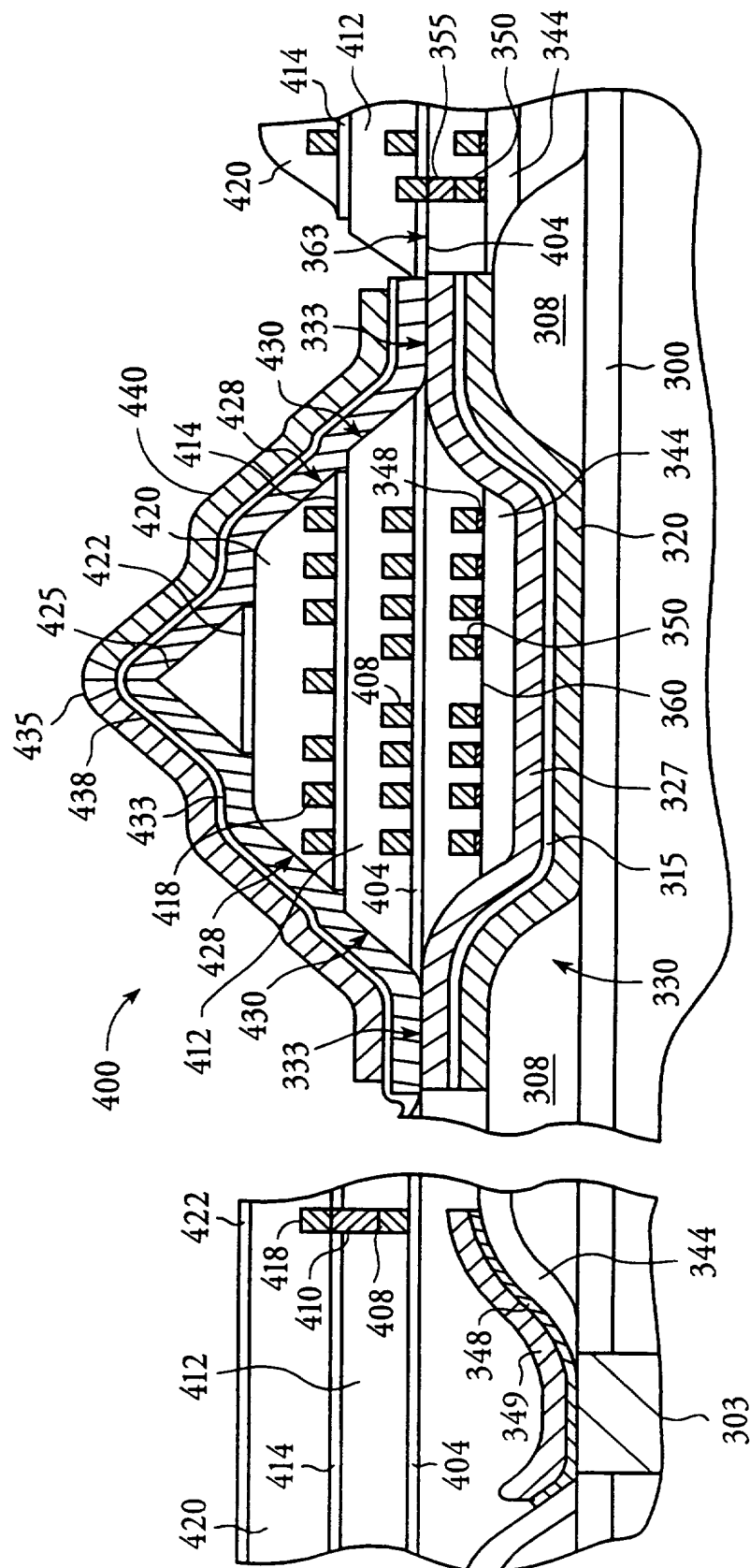


FIG. 27

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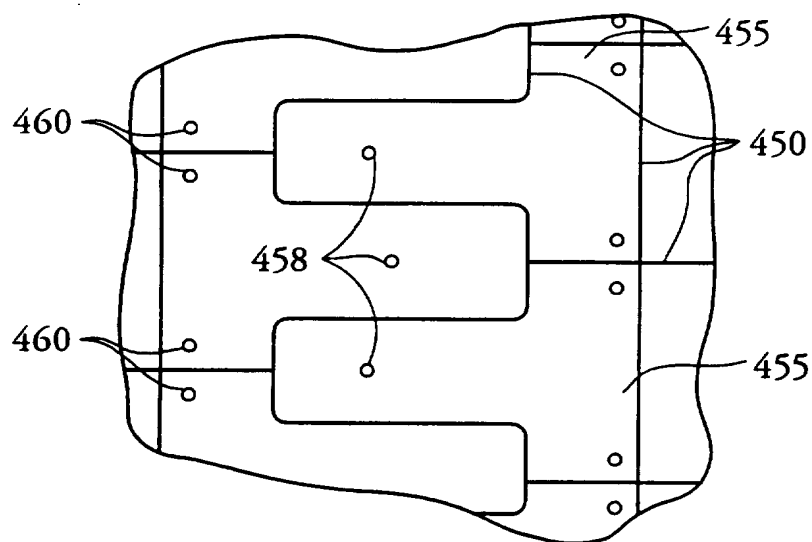


FIG. 28

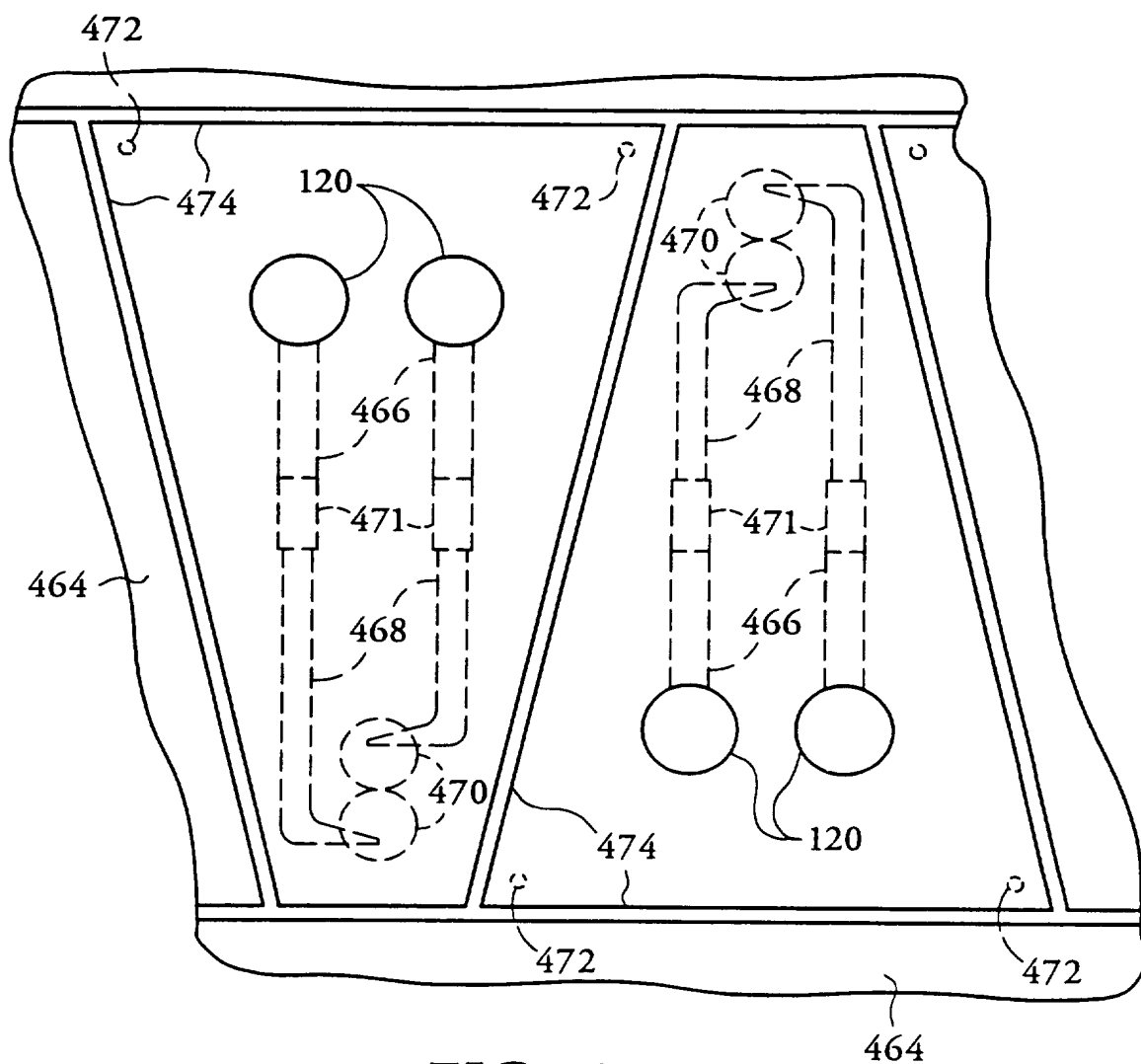


FIG. 29

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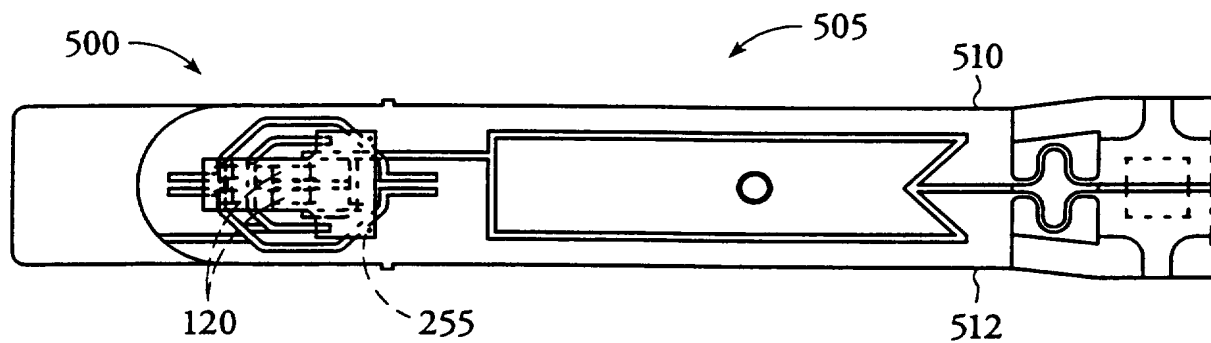


FIG. 30

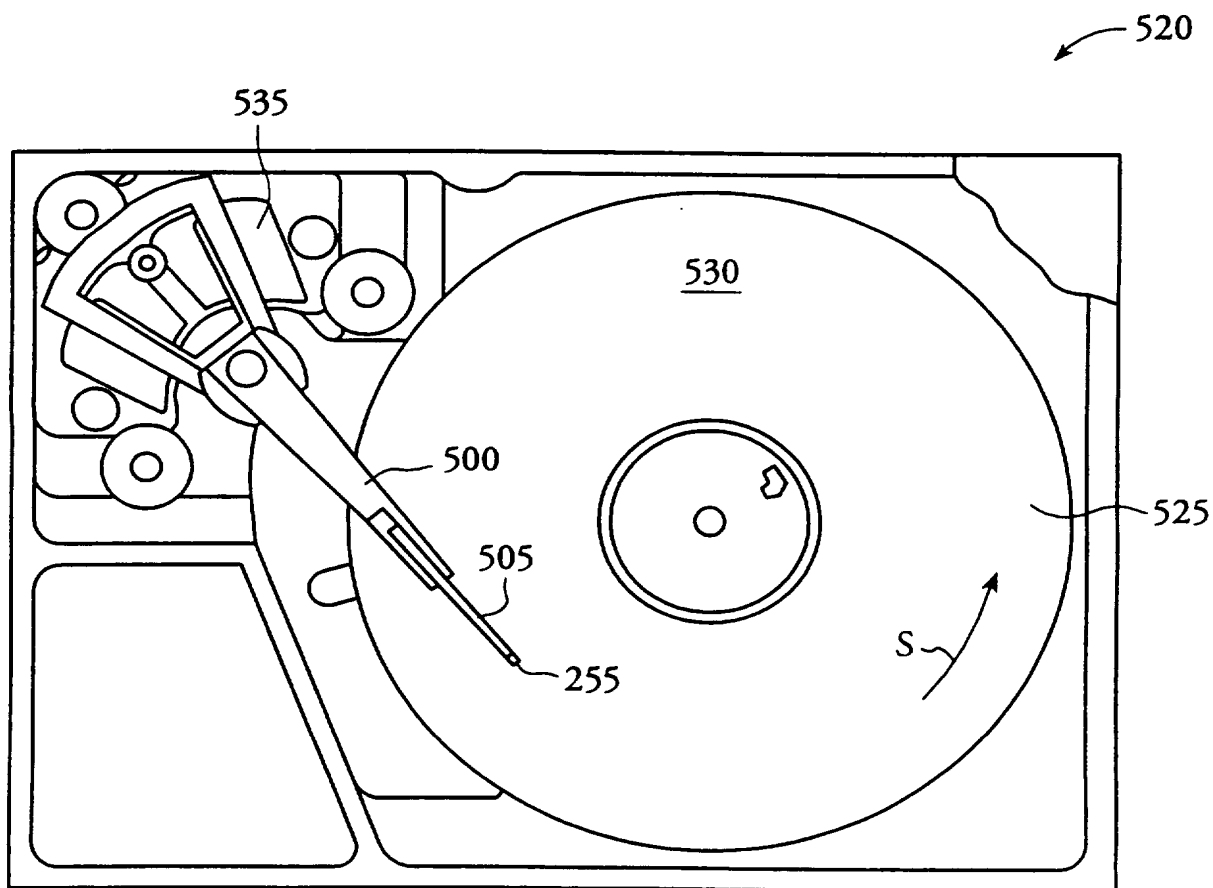


FIG. 31

# INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US96/14616

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :G11B 5/127, 5/187, 5/31

US CL :360/119, 122, 126

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 360/97.01, 97.02, 104, 110, 119, 122, 125, 126

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS, JAPANESE ABSTRACTS

search terms: magnetic head, poles, permeance, high magnetic saturation material, gap, poletips

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US, A, 5,111,351 (HAMILTON) 05 May 1992, see Figures 2 and 5.	1, 3, 8-10, 22, 24, 28 & 29 ----- 2, 4-7, 11-21, 23, 25-27 & 30
Y	US, A, 5,303,096 (KELLER) 12 April 1994, see Figure 3a.	2, 11-21, 23 & 27
Y	US, A, 5,432,645 (TERUNUMA ET AL) 11 July 1995, col. 1, lines 20-28.	4
Y	US, A, 5,075,956 (DAS) 31 December 1991, col. 2, lines 1-3 and Figure 22.	5, 6, 18, 19, 25 & 30

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:	*T	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
*A* document defining the general state of the art which is not considered to be of particular relevance	*X*	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
*E* earlier document published on or after the international filing date	*Y*	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
*L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	*Z*	document member of the same patent family
*O* document referring to an oral disclosure, use, exhibition or other means		
*P* document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search 21 DECEMBER 1996	Date of mailing of the international search report 14 JAN 1997
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**INTERNATIONAL SEARCH REPORT**

International application No.

PCT/US96/14616

**C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US, A, 5,436,781 (MATONO ET AL) 25 July 1995, see Figure 11.	7 & 26

**INTERNATIONAL SEARCH REPORT**International application No.  
PCT/US96/14616**Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)**

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:  
because they relate to subject matter not required to be searched by this Authority, namely:
  
2. ☐ Claims Nos.:  
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
  
3. ☐ Claims Nos.:  
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

**Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)**

This International Searching Authority found multiple inventions in this international application, as follows:

Please See Extra Sheet.

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☒ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:  
1-30
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

**Remark on Protest**

- ☐ The additional search fees were accompanied by the applicant's protest.  
☐ No protest accompanied the payment of additional search fees.

## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US96/14616

### BOX II. OBSERVATIONS WHERE UNITY OF INVENTION WAS LACKING

This ISA found multiple inventions as follows:

This application contains the following inventions or groups of inventions which are not so linked as to form a single inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fees must be paid.

Group I, claims 1-30, drawn to a transducer for a disk drive system.

Group II, claims 31-62, drawn to a method for forming a transducer for a disk drive system.

The inventions listed as Groups I and II do not relate to a single inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons: Group II species different methods for forming a transducer wherein each of the methods are not specially adapted to form the transducer of Group I because the different methods can be used to form other transducers that do not have the structure recited in Group I.

Additionally, Group I further includes claims directed to the following patentably distinct species of the claimed invention:

Species A, claims 2-4, 8-10, 12, 13, 15-17, 20, 21, 23, 24 and 27-29, directed to a first transducer.

Species B, claims 5, 7, 14, 26 and 30, directed to a transducer with a high magnetic saturation material adjacent the gap and plurality of magnetically permeable members separated by an magnetic layer.

Species C, claims 6, 18, 19 and 25, directed to a transducer with a clamshell shaped cross-section.

Currently, claims 1, 11 and 22 are generic.

The inventions listed as Species A-C do not meet the requirements for Unity of Invention for the following reasons: The listed species of inventions lack unity because there are no common "special technical features" with each claimed species. Species A requires the special technical features as shown in Figures 1-19 and 28-30, whereas Species B requires the special technical features as shown in Figures 21 and 22, and Species C requires the special technical features as shown in Figures 24-27. Thus, there are no common "special technical features" linking Species A-C with each other.